

**Investigating the Possibility of
Transparent Insulation Materials
as façade elements**

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A Dissertation submitted in part fulfilment of the degree of
Master of Science Built Environment
Environmental Design Engineering

University of London

2005

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Acknowledgements

I would like to thank my supervisor Dr. Ben Croxford for his guidance and dedication for the fulfilment of this work.

In addition I would like to thank my family and friends for their support all these years.

Abstract

This dissertation examines the possibility of using Transparent Insulation Materials (TIMs) as façade materials. Today's understanding of the increasing problem of Global Warming has led to the introduction of Building Regulations focused on the energy consumption of the buildings. Contemporary architecture trends promote the extensive use of glass because of its transparency and versatility. However glass is a major contributor in the energy demand of a building. For that reason, new materials like TIMs are investigated that will balance the architecture against the environmental behaviour of a building. This study has focused on the energy performance of a typical office building in the UK, with and without transparent insulation materials. Several cases were simulated and examined and all the cases using TIMs showed a better environmental performance than the case that did not. The comparisons between the model cases showed that when TIMs are applied in the North façade of the building its environmental performance is improved mainly because of the reduction in the lighting load. Additionally the good thermal performance characteristics of TIMs contribute in the decrease of heating energy. It looks that TIMs could be the ideal materials in the future for meeting both architectural needs and Regulations' requirements.

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1. Introduction

A recent report projects that the World's total energy consumption will rise by 59% between 1999 and 2020, up to a staggering value of 2×10^{14} KWh¹. A large part of the World's energy is spent on heating, cooling and lighting of buildings. The energy expenditure leads to release of CO₂, which is a major contributor to global warming. An increased use of air – conditioning, which mainly uses electricity, serves as clear evidence for human kind's rising demand on living standard and comfort. Simultaneously cheap fuel prices as well as the availability and low prices of air – conditioning systems contribute to this vast boost of their use. The increase occurs very generally even in countries that are commonly perceived as 'cold dominated' and is particularly noticeable in countries of South – East Asia. A major reason why air – conditioning is needed is that the windows of buildings allow a considerable amount of energy to enter. Half of this energy comes as visible light and the other half is infrared radiation. The main reason for having windows is that they create a visual contact between indoors and outdoors – a contact that is necessary for people's well being. Generally the installed windows and glass facades have increased in new buildings in recent years. This may be in some extent an architectural trend; however it goes along with the human needs and as a sequence there is further rise in CO₂ emissions². At present increasing environmental awareness has led to demand for increasingly efficient buildings with a view to achieving sustainable societies. Therefore there is a challenge for designers to try and balance the aesthetic benefits of glass against the environmental performance of the building. This need for balanced design as well as the growing emphasis on environmental responsibility of the building affected the creation of Building Regulations – which aim to improve the building design and its energy performance – and simultaneously made people investigate new materials and technologies. A result of these investigations is the manufacturing of transparent insulation materials (TIMs). TIMs are solar transparent, yet they provide good thermal insulation. These parameters make them a very interesting material with high potentials in energy conservation as well as meeting the architectural trends of today. However, these materials are currently in a development stage, thus improvement is continuous and several studies try to contribute in their advance and introduction to the global market. This dissertation will investigate

¹ Smart window and intelligent glass facades, C. G. Granqvist, 2002

² Smart window and intelligent glass facades, C. G. Granqvist, 2002

the possibility of TIMs as façade materials with the examination of the energy performance of an office type building in the UK. This analysis will be based on dynamic simulation of the various applications of TIM on a Building Regulations' nominal office building, after first reviewing the development and background of UK Building Regulations and transparent insulation.

2. Contemporary Architecture

2.1 Current Architectural Trends

The beautiful nature of glass, its versatility and transparency make it a common feature in today's urban landscape. Contemporary architecture is characterised by high – tech and minimalistic design approaches. Glass is a material that offers this simplicity to the architects today. It can be used to address the lightness of a structure as well as expose the form of the interior space of a building. Behind these design benefits it also functions as a connecting element of the inside and outside of a building promoting peoples' well being.

There are several architectural examples of the extensive use of glass that project the new technologies and functions that it can have as a material. One of them is Sir Norman Foster's Great Courtyard canopy at the centre of the British Museum.

The courtyard at the centre of the British Museum was one of London's long-lost spaces. Originally an open garden, soon after its completion in the mid-nineteenth century it was filled by the round Reading Room and its associated book stacks. Without this space the Museum was like a city without a park. This project is about its reinvention. In the absence of a centralised circulation system this popularity caused a critical level of congestion throughout the building and created a frustrating experience for the visitor. The departure of the British Library to St. Pancras provided the opportunity to clear away the book stacks and to recapture the courtyard to give the building a new public focus. The Great Court is entered from the Museum's principal level, and connects all the surrounding galleries. Within the space - the largest enclosed public space in Europe - there are information points, a bookshop and a café. At its heart is the magnificent space of the restored Reading Room, now an information centre and library of world cultures, which for the first time in its history is open to all. Broad staircases encircle the Reading Room and lead to a gallery for temporary exhibitions with a restaurant above. Below the level of the Court are the new Sainsbury African Galleries, an education centre, and facilities for schoolchildren.

The glazed canopy that makes all this possible is a fusion of state-of-the-art engineering and economy of form. Its unique geometry is designed to span the irregular gap between the drum of the Reading Room and the courtyard facades, and forms both the primary structure and the framing for the glazing, which is designed to maximise daylight and reduce solar gain. As a cultural

square, the Court also resonates beyond the confines of the Museum, forming a new link in the pedestrian route from the British Library to Covent Garden and the river. To complement this civic artery, the Museum's forecourt has been freed from cars and restored to form a new public space³.



Figure 1. Internal view of the glazed canopy above the Great Court of the British Museum.
(<http://www.fosterandpartners.com/internetsite/html/simple.html>)

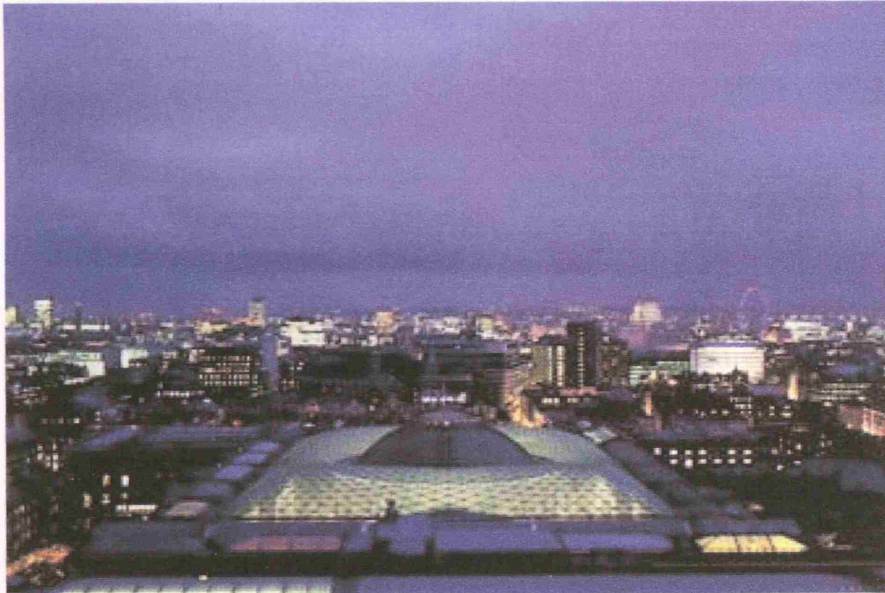


Figure 2. External view of the glazed canopy above the Great Court of the British Museum
(<http://www.fosterandpartners.com/internetsite/html/simple.html>)

³ <http://www.fosterandpartners.com/internetsite/html/simple.html>

Another example of the use of glass in contemporary architecture is Renzo Piano's New York Times Building. The story this building proposes is one of lightness and transparency. While designing a tower fulfils the greatest challenge in the upward reach, it also contributes a presence in the skyline that is both vibrant and changing with the winds. The 52 – storey building's basic shape is simple, primary, similarly to the Manhattan grid. It is slender, does not use mirrored or tinted glass, which render towers mysterious and hermetic subjects. On the contrary, the use of clear glass combined with a pattern of thin ceramic cylinders placed on a steel framework, positioned one to two feet in front of the glass, from bottom to top. This curtain wall will permit a high degree of energy efficiency in heating and cooling the building, and will make it get a different colour, according to the atmosphere: bluish after the rain, shimmering red at sunset (Figure 3)⁴.

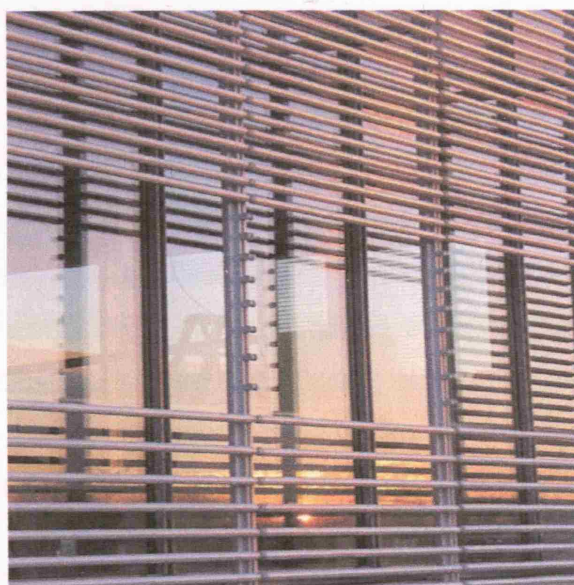


Figure 3. Detail picture of the glazed façade with the cylindrical shading system.
(<http://194.185.232.3/works/064/pictures.asp>)

The role that glass has in contemporary architecture is really important. However apart from offering major design advantages, glass is one of the major contributors of energy consumption in a building. This relationship of design and efficiency is an issue that seems to trouble architects today. For that reason Building Regulations have been introduced in order to control and guide architects into designs that follow the current trends and are energy efficient at the same time.

⁴ <http://194.185.232.3/works/064/descr.asp>

3. Building Regulations

3.1 The History and background of the Building Regulations

The Great Fire of London in 1666 encouraged the government of the time to issue building byelaws to prevent the spread of fire between buildings in London. In later years new Acts of the Parliament expanded their scope to deal with sanitation and public health. The Public Health Acts of 1936 extended building byelaws to the whole of the England and Wales. In 1965, these local byelaws were replaced by the national Building Regulations, which exist to this day. The 1965 Building Regulations were regularly updated and re-issued in full in 1972, and 1976. A New legislation framework set out in the Building Act 1984 provided the background to the current format (Simple Regulations plus Approved Documents giving technical guidance) of the Building Regulations that were created in 1985. The Building Regulations are divided up into 'Parts' with each 'Part' dealing with a specific technical, constructional or design topic. The modern Building Regulations were fully updated and re-issued in both 1992 and 2000. The technical guidance in the various 'Approved Documents' have also been amended and updated regularly since 1985. The current Building Regulations were issued by Parliament in December 2000 and they have been recently amended. The Building Regulations have extended the range of the Building Work that is now controlled with effect from 1st April 2002⁵.

3.2 Introduction to the Building Regulations

"Building Regulations ensure the health and safety of people in and around buildings (i.e. domestic, commercial and industrial) by providing functional requirements for building design and construction. The regulations also promote energy efficiency in buildings and contribute to meeting the needs of disabled people"⁶. The regulations are made under the rules provided in the Building Act 1984, and apply in England and Wales. The current edition of the regulations is "The Building Regulations 2000" (as amended) and the majority of building projects have to comply with them.

⁵ <http://www.gateshead.gov.uk/develandent/building.htm#1>

⁶ Building Regulations-Explanatory Booklet, Office of the Deputy Prime Minister, London, 2003

The Building Regulations contain various sections dealing with definitions, procedures and what is expected in terms of the technical performance of building work. These sections could:

- define what types of building, plumbing, and heating projects amount to 'Building Work' and make these subject to control under the Building Regulations
- specify what types of buildings are exempt from control under the Building Regulations
- set out the notification procedures to follow when starting, carrying out, and completing building work
- set out the 'requirements' with which the individual aspects of building design and construction must comply in the interests of the health and safety of building users, of energy conservation, and of access to and use of buildings⁷.

The 'requirements' that a building has to comply with are contained in Schedule 1 of the Building Regulations and are divided in fourteen 'parts'. The parts deal with individual aspects of building design and construction, with a range from structural matters, fire safety and energy conservation- to hygiene, sound insulation and access to and use of buildings. Alongside each of the fourteen parts there is a series of "Approved Documents" which contain:

- General guidance on the performance expected of materials and building work in order to comply with each of the requirements of the Building Regulations and
- Practical examples and solutions on how to achieve compliance for some of the more common building situations.

The fourteen parts and the relevant series of Approved Documents are listed below:

- Approved Document A – Structure
- Approved Document B – Fire safety
- Approved Document C – Site preparation and resistance
- Approved Document D – Toxic substances
- Approved Document E – Resistance to the passage of sound
- Approved Document F – Ventilation
- Approved Document G – Hygiene
- Approved Document H – Drainage and waste disposal
- Approved Document J – Combustion appliances and fuel storage systems
- Approved Document K – Protection from falling, collision and impact
- Approved Document L1 – Conservation of fuel and power in dwellings
- Approved Document L2 – Conservation of fuel and power in buildings other than dwellings
- Approved Document M – Access to and use of buildings
- Approved Document N – Glazing-Safety in relation to impact, opening and cleaning
- Approved Document P – Electrical safety⁸

⁷ Building Regulations-Explanatory Booklet, Office of the Deputy Prime Minister, London, 2003

3.3 Building Regulations and Construction Elements

In order to achieve energy efficiency in practice, the building and its services systems should be appropriately designed and constructed. Information should also be provided such that the performance of the building in use can be assessed. The above requirements are explored in the Approved Document L of the Building Regulations. In terms of the thermal performance of the building structure, the aim of this part of the Regulations is to limit the heat loss and, where appropriate, maximise the heat gains through the fabric of the building. In meeting this objective, Approved Document L suggests requirements of fabric insulation “which are set having regard to national standards of cost effectiveness, the need to avoid unacceptable technical risks and the need to provide flexibility for designers”. These requirements can be met if the thermal performance of the fabric elements of the building is no worse than the values set in Table 1⁹.

Standard U-values of construction elements	
Exposed Elements	U-value (w/m²K)
Pitched roof with insulation between rafters	0.20
Pitched roof with insulation between joists	0.16
Flat roof or roof with integral insulation	0.25
Walls, including basement walls	0.35
Floors, including ground floors and basement floors	0.25
Windows, roof windows and personnel doors (area weighted average for the whole building), glazing in metal frames	2.2
Windows, roof windows and personnel doors (area weighted average for the whole building), glazing in wood or PVC frames	2.0
Rooflights	2.2
Vehicle access and similar large doors	0.7

Table 1. Standard U-values of construction elements, as defined by the Approved Document L of the Building Regulations 2000.

Highly glazed façades are becoming an increasingly common feature in the present day due to the versatility, transparency and physical beauty of glass. This trend, however, should not minimize the environmental performance of the building envelope. Approved Document L is taking

⁸ Building Regulations-Explanatory Booklet, Office of the Deputy Prime Minister, London, 2003

⁹ The Building Regulations Part L2, Office of the Deputy Prime Minister, London, 2002

under consideration this trend and a provision to limit the rate of heat loss through the glazed elements of the building should be made by the designers. One way of complying would be to limit the total area of windows, doors and rooflights so that they do not exceed the values given in Table 2.

Maximum area of openings unless compensating measures are taken		
Building Type	Windows and doors as % of the area of the exposed wall	Rooflights as % of area of roof
Residential Buildings (when people temporarily or permanently reside)	30	20
Places of assembly, offices and shops	40	20
Industrial and storage buildings	15	20
Vehicle access doors and display windows and similar glazing	As required	20

Table 2. Maximum area of openings unless compensating measures are taken, as described by the Approved Document L of the Building Regulations 2000.

Another design concern when extensive glazing is used in a building is to avoid solar overheating. Part L states that a building should be constructed in such way that:

- Firstly, those occupied spaces that rely on natural ventilation should not overheat when subject to a moderate level of internal heat gain and
- Secondly, those spaces that incorporate mechanical ventilation or cooling do not require excessive cooling plant capacity to maintain the desired space conditions¹⁰.

For spaces that glazing is facing only one orientation a way of complying with the requirements would be to limit the area of glazing opening as a percentage of the internal area of the element under consideration to the values set in Table 3.

Maximum allowable area of glazing	
Orientation of opening	Maximum allowable area of opening %
N	50
NE/NW/S	40
E/SE/W/SW	32
Horizontal	12

Table 3. Maximum allowable area of glazing, as described by the Part L of the Building Regulations 2000.

¹⁰ The Building Regulations Part L2, Office of the Deputy Prime Minister, London, 2002

In the Energy White Paper the Government acknowledged global warming is a reality and, as part of the international effort to control and minimise this situation, goals were set out of putting the UK on a path to cutting the UK's carbon dioxide emissions - the main contributor to global-warming by some 60% by about 2050, with real progress by 2020. Carbon dioxide is released into the atmosphere whenever gas, oil, coal and wood are burned to provide heating, hot water, and the electricity needed for cooling, lighting and power. About a half of all CO₂ emissions come from buildings: about 30% from the 24 million dwellings in the UK and about 20% from other buildings. The Action Plan for Energy Efficiency points to a shortfall in progress to achieving the targets set for 2010 and beyond, and sets out a number of key initiatives that should overcome this.

Significant improvements in the Building Regulations energy efficiency provisions are seen in both the White Paper and the Action Plan as a major contributor towards achieving the target of a 20% reduction in carbon emissions by 2010.

The proposals for amending the Building Regulations would, if implemented, lead to an improvement in the energy efficiency of new buildings (and hence a reduction in the carbon emissions that it would be otherwise produced) of around 25% taking account of the possibilities for the application of improved standards for building fabric and heating, cooling and lighting services; and the availability of low and zero carbon systems. The key features in the proposals include setting performance standards for buildings as a whole rather than for construction and services elements and to firm up on pre-completion testing of air tightness. Improvements on a lesser scale would also be obtained whenever people carry out work on existing buildings. The flexibility in the proposed compliance method is constrained by a series of poorest acceptable benchmarks for the principal building fabric and heating, cooling and lighting services. The aim in this is to ensure that the performance of new buildings is reasonably robust against future alterations or replacement works (to prevent overall energy performance being largely dependent on single feature that might be removed at future date)¹¹. These improvements would come into effect in 2005 in line with the commitment in the Energy White Paper, and lead to a reduction of around 1.1 million tonnes of carbon per year in 2010. The consultation package also contains outline proposals for disseminating the changes to those who apply the Regulations and for further improvements that might become appropriate to introduce in 2010¹².

¹¹ Proposals for amending Part L of the Building Regulations and Implementing the Energy performance of Buildings Directive - A consultation document, Office of the Deputy Prime Minister, London, 2004

¹² http://www.odpm.gov.uk/stellent/groups/odpm_buildreg/documents/divisionhomepage/br0032.hcsp

The indicative U-values used in the 2005 proposals are shown in Table 4 alongside standards that exist in other European countries, which define the elemental limits. In this table it is suggested that currently in Europe there are technical solutions available and could be applied in the UK if the demands of cost-effectiveness, flexibility and avoidance of undue risk can be satisfied. The standards for walls and windows seem capable of significant improvement. However, for roofs and floors the scope for improvement seems less. It should be noted that the Swiss U-value standard for windows is significantly better than the proposed Part L standard. For the 2005 revision, only a marginal improvement is being proposed to new build U-value standards, with no change to the replacement window standard. It is therefore considered that it will be reasonable to expect a significant improvement in window U-values in 2010 for both new build and replacement glazing¹³.

Indicative U-values				
	U-values (w/m²K)			
	Wall	Roof	Floor	Window
Part L 2005 indicative	0.27	0.13	0.22	1.8
Part L 2005 worst acceptable element average	0.35	0.25	0.25	3.3
Denmark (due to be updated 2005/06)	0.2-0.3 depending on mass	0.15-0.2	0.2	1.8
Switzerland (target values)- lower values are adopted by some cantons	0.2	0.2	0.2	1.2

Table 4. Indicative U-values as they appear in the 2005 proposals alongside U-values from other European countries.

Another important area into the future is that of window performance. In the nondomestic arena, and especially for buildings with high internal loads, the summer performance of windows is as important as the winter. There will be an increasing need to develop window/shading combinations that deliver good light transmittance and occupant view but with low solar transmittance. External shading and spectrum selective coatings are likely to be the key in this area, with techniques for reflecting or distributing daylight deeper into the occupied space also

¹³ Proposals for amending Part L of the Building Regulations and Implementing the Energy performance of Buildings Directive - A consultation document, Office of the Deputy Prime Minister, London, July 2004

perhaps becoming important. Solar control is particularly important because it is one of the few variables the designer can use to reduce total summer heat gains to a level where natural ventilation can provide cooling for much or all of the year. With the climate getting warmer, the cooling potential of ventilation will reduce. This can be compensated by reduced heat gains to the space, the most important one of which is the solar gain through windows. Germany already has a requirement for mandatory shading on all facades with more than 30% glazing. Although a whole-building performance standard would not permit such prescriptive rules, it gives an indication of the sort of façade treatments that will be required in future if overall performance targets are to be met¹⁴.

¹⁴ Proposals for amending Part L of the Building Regulations and Implementing the Energy performance of Buildings Directive - A consultation document, Office of the Deputy Prime Minister, London, July 2004

4. Transparent Insulation Materials (TIMs)

4.1 Introduction to Transparent Insulation Materials

Thermal insulation is a material or combination of materials that, when properly applied on a building's envelope, opposes the rate of heat flow by means of conduction, convection and radiation. In its simplest means it retards heat flow into or out of a building due to its high thermal resistance¹⁵. In industry, thermal insulation serves several important functions such as preventing heat leakage, saving energy, control of temperature and thermal energy storage. When TIMS are used in a window the components can be referred to as a daylight wall. Conventional insulation materials are often opaque and porous, and can be classified into fibrous, cellular, granular and reflecting types. Transparent insulation materials (TIM) represent a new class of thermal insulation wherein air gaps and evacuated spaces are used to reduce the unwanted heat losses. It consists of a transparent cellular array immersed in an air layer. The air layers are similar to conventional insulation materials with regard to the placement of air gaps in the transparent solid media. TIMs are solar transparent, yet they provide good thermal insulation. They hold great promise for application in increasing the solar gain of outdoor thermal energy systems. Solar transmittance and heat loss coefficient are the two parameters used for their characterization. The fundamental physical principle used in TIM is the wavelength difference between solar radiation, which is received by the absorber, and IR radiation, which is emitted by the absorber¹⁶.

Transparent window glazing and transparent sheets above solar collector absorbers are perhaps the most common TIMs used today. Since the 1970s high performance transparent insulation materials such as honeycomb and aerogel have been developed for solar energy applications. Four types of solid transparent materials including flexible polymer foils; polymer honeycomb materials; bubbles, foam and fibres; and inorganic microporous materials such as silica aerogels are shown in Figure 1. If the honeycomb cross-section is small to the cell length, it can then be described as a capillary structure. Foils and aerogel can be almost invisible to the eye, while honeycomb, bubbles, foam and fibres cause reflection and scattering, and hence a limited

¹⁵ Performance characteristics and practical applications of common building thermal insulation materials, Dr Mohammad S. Al-Homoud, 2004

¹⁶ Solar transparent insulation materials: a review, N. D. Kaushika, K. Sumathy, 2003

transmittance. Thus the first group of materials (i.e. foils and aerogel) are of interest when undisturbed vision is required, such as many windows. On the other hand the second group of materials (i.e. Honeycomb, bubbles, foam and fibres) can be found in applications such as transparent wall cladding and solar collectors. The materials can be used in vertical, horizontal, or inclined positions depending on the type of application¹⁷.

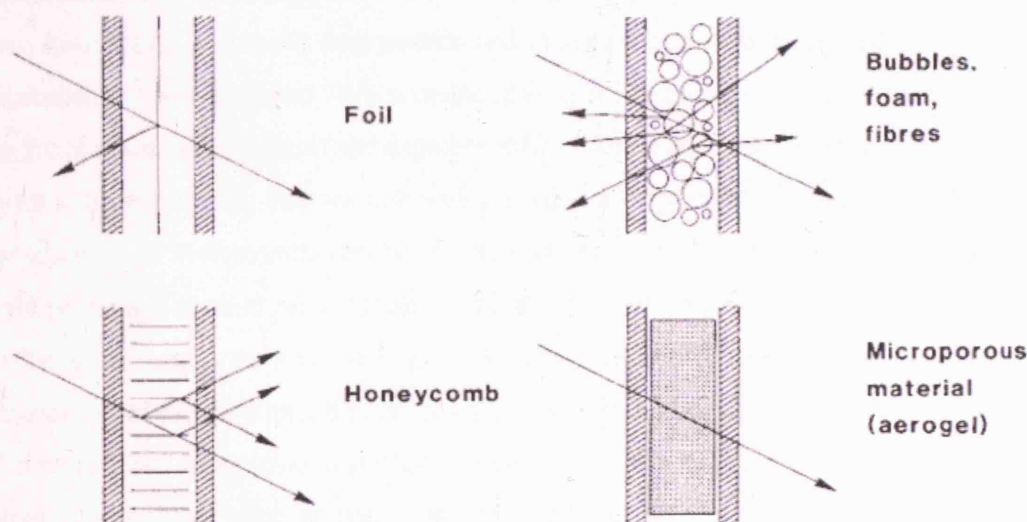


Figure 4. Principles of four different types of solid transparent insulation materials placed between glass panels. The arrows signify the light rays. Reflections at the glass surfaces are not shown. (Solar energy materials, C. G. Granqvist, 2003)

4.2 Historical Background

In solar energy context, Veinberg and Veinberg investigated the use of “deep narrow meshes” as solar transparent honeycomb insulation in solar absorbers¹⁸. For decades investigations to improve the properties of transparent insulations have been carried out. In the 1960s honeycomb structures as transparent insulation material were investigated by Hollands (1965) and other authors. Tabor (1969) presented a concise picture of cellular (honeycomb) arrays, indicating that for a more successful use of honeycomb insulation better materials and manufacturing techniques should be discovered. Charters and Guthrie (1982) studied the performance of a flat-plate collector with a honeycomb application as a convection suppression device. However, this application proved not very successful due to the demanding characteristics

¹⁷ Solar energy materials, C. G. Granqvist, 2003

¹⁸ Solar transparent insulation materials: a review, N. D. Kaushika, K. Sumathy, 2003

of the materials and fabrication methods. In the early 1980s, a new concept was proposed for a non-convective solar pond using the honeycomb as transparent insulation. It was an attractive alternative to the salt gradient solar pond. This led to a great deal of extensive experimental as well as theoretical research work up to now, in order to improve this type of material (e.g. Pflüger, 1988; Platzer, 1988). Several new configurations of TIM have been researched simultaneously. Optical transmittance and reflectance of several translucent samples over a solar wavelength range has been investigated and many new plastics and manufacturing techniques have been tried¹⁹. The application of these improved TIMs on external walls as a passive solar heating element similar to the Trombe wall was proposed and experimentally investigated²⁰. Honeycomb material allows thick layers to be constructed that are both well insulating and highly transparent to sunlight. The high transparency of honeycombs can be understood from the forward reflection at the honeycomb walls, which are oriented perpendicular to the absorber. The insulating properties of honeycombs, on the other hand, are achieved by keeping the honeycomb cell size small enough so that convective and radiative heat transfer are suppressed²¹. As frequently occurs with the resurgence of research on honeycomb insulation, alternative means were also explored. One of these alternative means is silica aerogel. The first systematic studies on transparent silica monolithic aerogels were done by Moutel. The aim of his work was to provide silica aerogels for the construction of Cerenkov radiators. Since then several studies mainly focused on the chemical structure of the silica aerogel and on the different methods of preparing this material led to better transparencies and insulation properties. Monolithic silica aerogel is a highly porous material with a sizing range of the pore diameters of 10 - 100 nm. The porosity is above 90%, which combined with the nanometre pore size makes the aerogel a highly insulating material with a thermal conductivity lower than this of still air. Alongside the low thermal conductivity a high solar energy and daylight transmittance is achieved. These properties make monolithic silica aerogel an ideal material for use in highly energy efficient windows²² and it is interesting studying it in a greater detail.

¹⁹ Solar transparent insulation materials: a review, N. D. Kaushika, K. Sumathy, 2003

²⁰ TIM-PCM external wall system for solar space heating and daylighting, H. Manz, A. Goetzberger, P. W. Egolf, P. Suter, 1997

²¹ Heat transfer across corrugated sheets and honeycomb transparent insulation, H. Suehrcke, D. Daldehog, J. A. Harris, R. W. Lowe, 2004

²² Super insulating aerogel glazing, J. M. Schultz, K. I. Jensen, F. H. Kristiansen, 2005

4.3 The Aerogel Glazing

The compression strength of aerogel is sufficient to take up the atmospheric pressure if evacuated. On the other hand the tensile strength of the material is very low which makes it fragile thus if in contact with liquid water the surface tension in the pores would demolish the aerogel structure²³. As a result, the use of silica aerogel for window glazing requires the aerogel to be protected against water and tensile stress. This is achievable by "placing the aerogel between two layers of glass and applying a gas and vapour tight rim seal. When evacuated to a rough vacuum only compression stresses will be present in the aerogel due to the external atmospheric pressure". The developed aerogel glazing has a total solar energy transmittance (g-value) higher than plain double glazing and at the same time has a heat loss coefficient equal to the best triple layered gas filled glazing units. The advantage of aerogel windows in comparison to commercial available low energy glazing, for which reduction in U-value is achieved by multiple layers of glass and low emissive coatings – measures that all reduce the solar energy and daylight transmittance, is shown in Figure 2²⁴.

Monolithic silica aerogel is the only known material that has this excellent combination of high solar and light transmittance and low thermal conductivity – combination that makes it possible to achieve a net energy gain during the heating season for north facing windows in a northern European climate²⁵. In cold northern climate, little or no solar radiation is received during the coldest months when actually the heating demand is at its peak. Therefore, solar energy cannot be used for heating in this period, which lasts approximately 4 months. Due to this 'dark and cold period', good insulation is the most important energy issue. Solar energy can be useful during the rest of the year. Generally, the design of low energy buildings is approached differently in northern and southern countries. In the south, solar energy can be used for heating during the winter. During summer season, shading is important in order to avoid overheating. In the north solar energy can be exploited in the spring, the autumn and parts of the summer. During the winter season, good insulation is vital to prevent heat losses. The solar radiation received through windows in northern climates is therefore important both for heating and well being of people. Thus the windows should have both high thermal resistance and high transmittance of solar radiation, so that large heat

²³ Super insulating aerogel glazing, J. M. Schultz, K. I. Jensen, F. H. Kristiansen, 2005

²⁴ Super insulating aerogel glazing, J. M. Schultz, K. I. Jensen, F. H. Kristiansen, 2005

²⁵ Super insulating aerogel glazing, J. M. Schultz, K. I. Jensen, F. H. Kristiansen, 2005

losses are prevented during the winter and a lot of solar energy is received during the spring and autumn. This might be obtained by the use of TIMs²⁶.

Theoretically the small porous diameters mentioned above make it possible to create silica aerogel that is perfectly transparent without major distortion of the transmitted light. However, in practice, several difficulties arise during the production process of the material. Many local disorders in the material result in scattering of the transmitted light, mainly in the blue part of the visible spectrum. This scattering gives objects a hazy look when observed through the aerogel and also changes the colours in such way that the aerogel appears slightly blue when the background is black or dark and slightly yellow when the background is white or light²⁷.

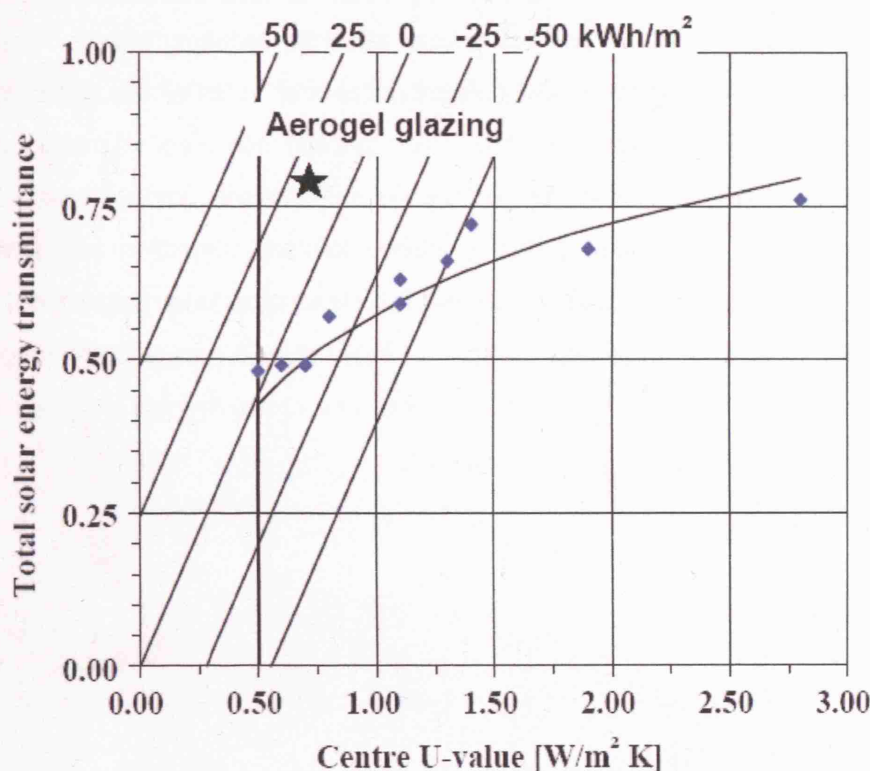


Figure 5. Thermal and solar properties of aerogel glazing (15mm aerogel) compared with typical commercially available low energy glazing. The dots mark the values for specific glazing units. The solid curved line shows the tendency in the traditional glazing development. The straight lines show the net energy balance during the heating season for a north facing glazing in a Danish climate. (Super insulating aerogel glazing, J. M. Schultz, K. I. Jensen, F. H. Kristiansen, 2005)

²⁶The use of transparent insulation in low energy dwellings in cold climates, A. G. Lien, A. G. Hestnes, O. Aschehoug, 1997

²⁷ Monolithic silica aerogel in superinsulating glazings, K. Duer, S. Svendsen, 1998

4.4 Case studies of TIM application

Tests and measurements of the first European installation of "Nanogel" translucent aerogel daylighting panels in a school sports hall in Buchwiesen, Zurich confirmed the data initially estimated by architect Arnold Amsler. The sports hall installation demonstrates even light distribution with consistent brightness and ability to maintain comfortable climatic conditions in summer and winter. Evaluation and testing at the Buchwiesen sports hall were conducted by Peter Hartmann, Technical University (ETH) Zurich and supported by summer comfort measurements by the Department of Building Physics of the EMPA. "Scobatherm Polyester" translucent building elements incorporating "Nanogel" hydrophobic silica aerogel – manufactured exclusively by "Cabot Corporation"²⁸ – were produced by Swiss building material company "Scobalit" and installed in 1000m² of roofing and 350m² of north-facing facade of the sports hall. Uniformly diffused light was a key requirement for the school building project and Amsler was impressed with the potential of the "Scobatherm" building elements to maximise the advantages of daylight. Zurich officials were also impressed by the thermal insulation benefits of "Scobatherm" for the potential energy and cost savings. The planning documents for the hall specified a value of 0.03-0.05, or 3-5%, for the hall's daylight quotient parameter. This is usually a difficult specification to achieve on a longitudinal elevation in a sports hall with normal fenestration²⁹ (Figure 3).

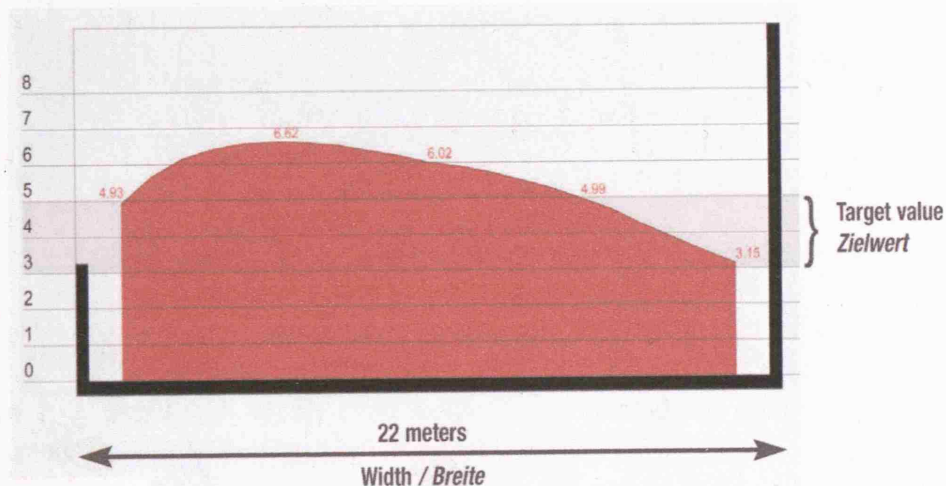


Figure 6. The planning documents for the hall specified a value of 0.03-0.05 or 3-5%, for the hall's daylight quotient parameter. (<http://www.emg.nl/en/prfitem.asp?id=4630>)

²⁸ <http://www.cabot-corp.com>

²⁹ <http://www.emg.nl/en/prfitem.asp?id=4630>

Although the occupied area of the Buchwiesen sports hall was located below ground level, the “Nanogel” filled product allowed daylight quotient to fill the hall’s complete area. In fact, the daylight quotient was exceeded in the central area of the hall. Figure 4 illustrates the interior of the building of the building and confirms the very even light distribution within the Buchwiesen sports hall. Brightness measurements plotted onto the photograph (Figure 4), taken on a sunny, cloudless day in March, are all in a similar range for the hall’s playing area, ceiling and rear concrete wall. This provides very favourable conditions for activities played longitudinally. The light conditions are slightly less favourable for games played transversely because there are darker areas along the longitudinal walls. However, these light conditions are still within a comfortable range in contrast to glare. Brightness measurements taken over a similar period at a conventionally built sports hall of a canton school at Winterthur, showed considerable variation, demonstrating the contrasts that create glare for the hall’s users³⁰.



Figure 7. A photograph of the sport hall’s interior showing the different brightness measurements. (<http://www.emg.nl/en/prfitem.asp?id=4630>)

The climate in the hall during the summer months was the area of greatest uncertainty for the Buchwiesen project. This concern was partly reduced by positioning the building so that it received as little direct sunlight as possible and when there was sunlight, it was at a low angle.

³⁰ <http://www.emg.nl/en/prfitem.asp?id=4630>

Temperature measurements were taken inside the hall during 10 days in July when it was not in use and when outside temperatures, not in direct sunlight, rose to 30-35°C (Figure 5). When a combination of the hall's programmed night ventilation with open windows for about 40% of the day, the inside temperatures rose 2-4°C above outside temperatures. When the windows were left open at all times during the day, except when it was raining, the internal temperature was always below the external reading by an average of 4°C. The maximum temperature in the hall was reached at 17.00 hours, well outside normal primary school teaching hours. The tests demonstrate that a marked improvement in the climatic conditions could be achieved in summer by optimising the ventilation. Even with peak temperatures outside of 33°C, the hall's users would be able to stay inside for longer hours at temperatures below 26°C. Architect Arnold Amsler's opinion was that "the comparison of daylight and glare between a sports hall of standard design and that built incorporating the Scobatherm building elements is strongly in favour of the Buchwiesen project, its bright atmosphere being particularly impressive". Additionally he believes "further improvements in comfort levels and operating conditions are possible. They will require more intensive computer simulation in terms of the building's positioning and its design, plus modification, if possible, to the U-value of the "Scobatherm" building elements"³¹.

³¹ <http://www.sfp-news.com/SFP-newsIssue56.pdf>

The Buchwiesen project is the first European installation for "Nanogel" aerogel products. The "Scobatherm" roof elements installed in the sports arena measure 2000mm x 2200mm and the façade panels are 5000mm x 2500mm. Both are 51.4mm in thickness. They have a U-value of 0.48W/m²K, a G-value of 25% and a light transmission of 25%.

Apart from this practical example of aerogel insulation application, there have been several theoretical and experimental studies on aerogel insulation. In the most recent one, J. M. Schultz et al. studied "Super Insulating Aerogel Glazing". This project is focusing on the application results of a previous and current European Union funded project on super-insulating glazing based on monolithic silica aerogel. Window prototypes were created, with a size of approximately 55 x 55m² with 15mm evacuated aerogel between two layers of low-iron glass. Anti-reflective treatment of the glass and heat-treatment of the aerogel increases the visible quality and the solar energy transmittance. A low-conductive rim solution with the required vacuum properties has been developed along with a reliable assembly and evacuation process. The prototypes have a centre heat loss coefficient below 0.7 W/m²K and solar transmittance of 76%³². The investigation and development of the prototypes took place in the laboratory. The prototypes were mainly built for testing the optical and thermal properties as well as looking the assembly process at a pre-industrial stage. This step by step procedure is as follows:

- The heat treated aerogel (T =425°C) is placed on the lower glass pane.
- A butyl sealant strip is applied to one side of the polystyrene rods with foil, which are placed along the aerogel edges with the butyl facing the lower glass and pressed slightly in position.
- The corners are joined with butyl sealant and a butyl sealant strip is applied on top of the polystyrene rods.
- The top glass pane is centred in the vacuum chamber and small self-adhesive metal disk are placed on the top glass pane opposite to electromagnets in the vacuum chamber lid. The lid is closed and the magnets are activated in which way the upper glass is fixed to the lid in the right position.
- The vacuum chamber lid is opened and the lower glazing with aerogel and rim solution is placed in the vacuum chamber.

³² Super insulating aerogel glazing, J. M. Schultz, K. I. Jensen, F. H. Kristiansen, 2005

- The vacuum chamber lid is closed and the evacuation started. The evacuation is continued until a pressure of approximately 1 hPa has been maintained for 5 min. Total evacuation time is approximately 30 min.
- The upper glass pane is lowered and pressed firmly against the aerogel and rim seal solution to make an airtight connection between glass panes and rim seal.
- The chamber is gently vented and the atmospheric pressure further compresses the glazing securing the complete compression of the butyl sealing between the foil and the glass panes³³.

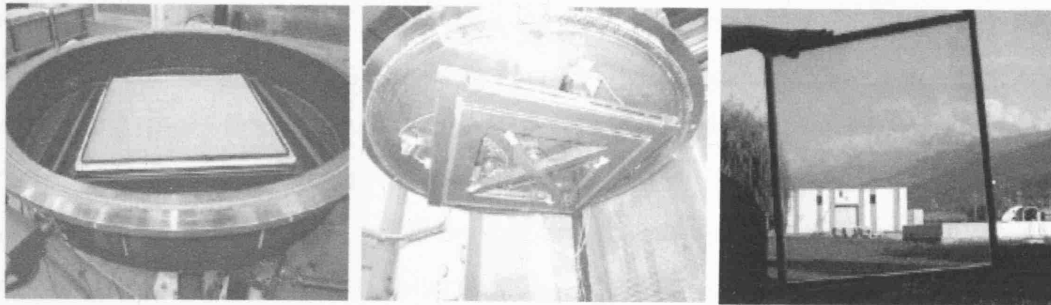


Figure 9. The assembly procedure of an aerogel glazing prototype. From the left, lower glass, aerogel and rim seal in vacuum chamber. Then the upper glass fixed to lid of vacuum chamber by means of electromagnets and the final aerogel glazing. (Super insulating aerogel glazing, J. M. Schultz, K. I. Jensen, F. H. Kristiansen, 2005)

The lifetime of aerogel glazing is expected to be between 20 and 25 years despite the increased thermal stresses caused by the good insulating properties.

Part of this project was also a practical application of the prototype glazing and the way that they perform at a new single family house in the Danish climate. The study showed that when aerogel glazing (U -value = $0.5 \text{ W/m}^2\text{K}$, G -value = 0.75) replaces convectional triple – Argon filled glazing (U -value = $0.5 \text{ W/m}^2\text{K}$, G -value = 0.45), the resulting annual energy saving is 2300 kWh/year. Similarly for a low-energy house the savings are reduced to 1600kWh/a, but in this case it corresponds to 25% of the annual heating demand. A high solar transmittance may result in high indoor temperatures during summertime even in colder climates and solar shading and enhanced venting may be needed.

However, the optical quality of aerogel glazing is not at the same level as conventional glazing units especially not if exposed to non-perpendicular direct radiation where some diffusion of

³³ Super insulating aerogel glazing, J. M. Schultz, K. I. Jensen, F. H. Kristiansen, 2005

the radiation in the aerogel occurs and makes the outlook hazy. But the optical quality has been improved considerably, making aerogel glazing an excellent option for improved daylight utilisation combined with a fair outlook by placing large areas of aerogel glazing in north facades. Due to the very good insulation properties and the high solar and daylight transmittance this can be done without energy loss or even with energy gain, which cannot be obtained with any other known glazing or daylight component options. Furthermore, results show that the daylight could be at a more constant as well as pleasant level during the daytime compared to a south orientation and the excess temperature problems could be reduced considerably. Thus, the application of aerogel glazing in new buildings could offer the possibility of increase the north facing glazing area and decrease the south facing one. Hereby, the capital cost for overheating prevention, e.g. shading devices, air conditioning, enhanced venting, etc., can be significantly reduced. However, despite the promising results already achieved by this experimental study, the research is still focusing on further improvement of the optical quality through detailed studies of the aerogel process and a post heat treatment aiming at an optical quality comparable to ordinary glass. In parallel focus has been put on cost estimation for aerogel glazing made in an industrial production scale for evaluation of market potential compared to conventional sealed glazing units³⁴. More projects using transparent insulation materials are shown in Appendix 1.

³⁴ Super insulating aerogel glazing, J. M. Schultz, K. I. Jensen, F. H. Kristiansen, 2005

5. Computer Simulation

5.1 Aims of the study

The aims of this study are:

- To investigate the energy performance of TIMs in a typical office in the UK.
- To look at the optimum amount of TIMs that can be used on a building façade, and examine which orientation can be the most energy beneficial.
- To show that TIMs can, in the future, meet the architectural trends of transparency and light, as well as meeting the requirements of the Building Regulations.

5.2 Methodology

The aims set previously, can be met with the use of dynamic computer simulation. The procedure that will be followed is firstly to simulate the energy performance of a typical office in the UK, using construction materials and methods that meet the requirements of the Building Regulations as well as the ECON19 standards and it will be referred to as 'Nominal Building' and it will be the base case. The second stage will be to substitute the typical construction materials with transparent insulation ones for each façade of the building (i.e. 'transparent insulation on the North façade'), focusing as well at several percentages of façade area that transparent insulation can be applied to (i.e. 'transparent insulation on 50% of the South façade'). These simulation models and cases can be then analysed and compared with the first typical case in terms of energy performance. The program that will be used for the simulations is TAS and the analysis and comparisons can be achieved with the use of Excel spreadsheets.

5.2.1 Description of TAS simulation program

TAS is a software tool, which simulates the thermal performance of buildings. The main applications of the program are in assessment of environmental performance, natural ventilation analysis, prediction of energy consumption, plant sizing, analysis of energy conservation options and energy targeting. TAS is linked to the 3D modeler, 3D-TAS. The fundamental approach adopted by TAS is dynamic simulation. This technique traces the thermal state of the building

through a series of hourly snapshots, providing the user with a detailed picture of the way the building will perform, not only under extreme design conditions, but also throughout a typical year. This approach allows the influences of the numerous thermal processes occurring in the building, their timing, location and interaction, to be properly accounted for.

Conduction in the fabric of the building is treated dynamically using a method delivered by ASHRAE response factor technique. This efficient computational procedure calculates conductive heat flows at the surfaces of walls and other building elements as functions of the temperature histories at those surfaces. Constructions of up to 12 layers may be treated, where each layer maybe composed of an opaque material, a transparent material or a gas. Databases of materials and constructions are available, and formation of new materials and constructions is also possible. Convection at building surfaces is treated using a combination of empirical and theoretical relationships relating convective heat flow to temperature difference, surface orientation, and, in the case of external convection, wind speed. Long-wave radiation exchange is modeled using the Stefan – Boltzmann law, using surface emissivities from the materials database. Long-wave radiation from the sky and the ground is treated using empirical relationships. Solar radiation absorbed, reflected and transmitted by each element of the building is computed from solar data on the weather file. The calculation entails resolving the radiation into direct and diffuse components and calculating the incident fluxes using knowledge of sun position and empirical models of sky radiation. Absorption, reflection and transmission are then computed from the thermophysical properties of the building elements. External shading and the tracking of sun patches around room surfaces may be included at the user's option. Internal conditions, which include room gains from lights, equipment and occupants as well as infiltration rates and plant operation specifications, are grouped together in profiles, which are applied to the various zones of the building. Internal conditions profiles may be stored in a database for later retrieval. Gains are modeled by resolving them into radiant and convective portions. The convective portion is injected into the zone air, whilst the radiant gains are distributed amongst the zone's surfaces. Infiltration, ventilation and air movement between the various zones of the building causes a transfer of heat between the appropriate air masses which is represented by terms involving the mass flow, the temperature difference and the heat capacity of air. TAS offers the capability to calculate natural ventilation air flows arising from wind and stack pressures. Solar radiation entering a zone through transparent building components falls on internal surfaces, where it may be absorbed, reflected or transmitted

depending on the surfaces' properties. Distribution of reflected and transmitted solar radiation continues until the radiation has been accounted for. Heating and cooling plant is represented by plant capacities, setpoints and control bands. Like gains, plant inputs may have both radiant and convective portions. TAS solves the sensible heat balance for a zone by setting up equations representing the individual energy balances for the air and each of the surrounding surfaces. These equations are then combined with further equations representing the energy balances at the external surfaces, and the whole equation set is solved simultaneously to generate air temperatures, surface temperatures and room loads. This procedure is repeated for each hour of the simulation. A latent balance is also performed for each zone, which takes account of latent gains, moisture transfer by air movement and the operation of humidification and dehumidification plant³⁵.

5.2.2 Description of the 3D TAS model

The building is a typical five – storey, air – conditioned, open plan office in UK. The office is approximately 28m long and 15m wide. The floor to ceiling height is set at 3.5m. A 3D representation of the office as it appears in TAS is shown in figure 7. The office is modeled in an urban environment with buildings across (to the North and South) and attached to it (East and West sides). There are ten windows for every floor in each façade (North and South). The windows are approximately 1.5m tall and 1.5m wide.

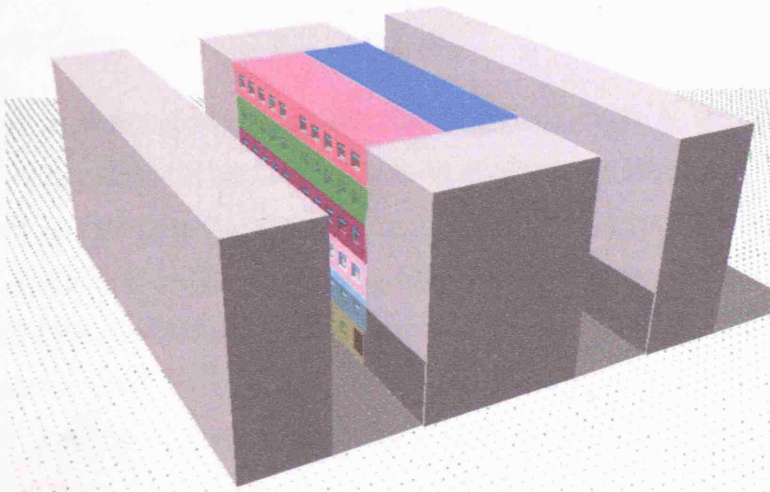


Figure 10. The 3D model of the office as it appears in TAS

³⁵ Notes from TAS tutorials, Dr. Ben Croxford, Lecture on 26/10/2004

As mentioned above, TAS works by tracing the thermal state of the building by dynamic analysis of the different zones of the building. Therefore, it is important in order to achieve the required simulation results to set accurate and strategic zoning. In this study the models have been split into two equal-sized zones per floor, in the North and South sides of the building (Figure 8).

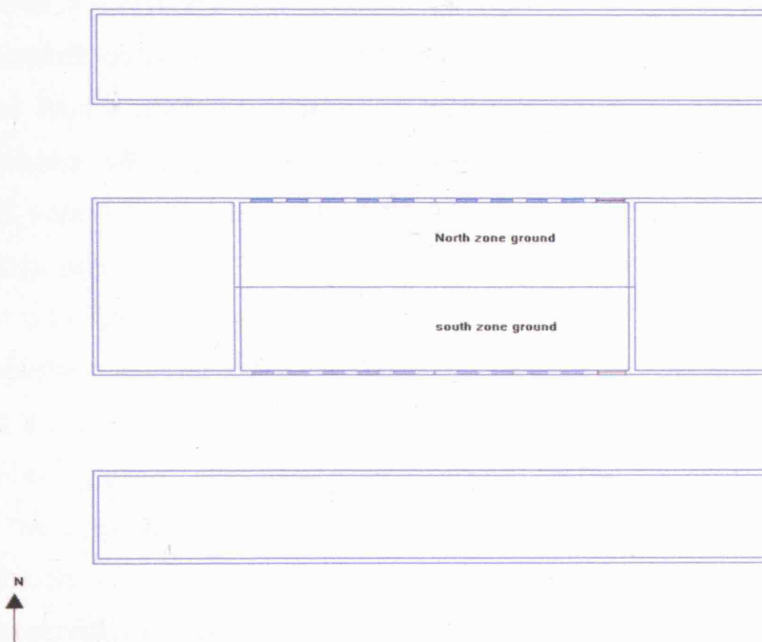


Figure 11. The North and South zones as they appear on TAS

5.2.3 Base Case: The Nominal Building

The nominal building is, as described, the basic model of this study and represents a typical air – conditioned UK office, which in terms of energy performance and construction complies with the current Building Regulations. The dynamic simulation of this model in TAS Building Simulator is going to be the base case, with which the other cases and simulations will be compared. At this point several decisions and assumptions have been made in order to achieve the desired results. Firstly the calendar of the simulation is broken down into 'weekdays' and 'weekends', therefore corresponding to real – life office use (i.e. open during weekdays, closed during weekends). The weather file used was "UK_Heathrow_EWY", which is recorded at Heathrow weather station from October of 1979 to September 1980.

The next step is to assign different constructions for the different building elements. The decision for collecting the constructions was made based on the fact that the nominal building has to comply with the current Building Regulations, therefore the U-values should be within the range described previously in Table 1. All the external walls are built with a construction of an overall U-value of approximately $0.35\text{W/m}^2\text{K}$. The flat roof construction is $0.26\text{W/m}^2\text{K}$ while the ground floor has a U-value of $0.21\text{W/m}^2\text{K}$. The windows have a U-value of approximately $2.1\text{W/m}^2\text{K}$ and the internal floors/ceilings a U-value of $0.75\text{W/m}^2\text{K}$.

The internal conditions selected are such that represent a basic air conditioned office during 'weekdays' with a schedule set at office hours, i.e. from 8.00 – 18.00. Infiltration is assumed at 0.5ACH while the ventilation is 0.8ACH based on the CIBSE Guide B2 requirements of 8lt/sec/person when there is 1 person for every 10m^2 of floor area. Lighting gains are again referenced to the CIBSE Guide at 12W/m^2 . Occupancy sensible and latent gains are 10W/m^2 and 5W/m^2 respectively while equipment sensible and latent gains are 15W/m^2 and zero respectively. A thermostat is present with an upper limit of 25°C during the cooling period and a lower of 21°C during the heating period. All of these assumptions and settings are concentrated in Tables 5 and 6. During the 'weekends' another set of internal conditions has been selected, representing a closed office. No heating, cooling or ventilation is provided during this time. Infiltration remains the same as previously at 0.5ACH.

Once the model contains sufficient information, a dynamic simulation may be run. The simulation, for a selected period from the weather data, provides detailed results of building performance over that entire period. Simulation results can give useful information on energy consumption and internal conditions.

Assumptions – TAS Settings

Internal Conditions	Ventilation	Infiltration	Temperature		Lighting	Occupancy		Equipment	
	0.8 ACH	0.5 ACH	Upper 25°C	Lower 21°C	12W/m^2	Sens. 10W/m^2	Lat. 5W/m^2	Sens. 15W/m^2	Lat. 0W/m^2

Table 5. The assumptions for the internal conditions of the office.

Assumptions – TAS Settings

U-values ($\text{W/m}^2\text{K}$)	Walls	Windows	Ground Floor	Roof	Floors/ceilings
	0.35	2.1	0.21	0.26	0.75

Table 6. The assumptions for the U-values of the different building elements of the office.

5.2.4 Case 1: Transparent Insulation on the North Façade of the Building

This case represents the same office building in terms of size, window location and surroundings however, the opaque wall construction of the North façade has been substituted with transparent insulation material and the South façade is superinsulated. The assumed transparent insulation construction is based on a newly developed aerogel glazing that has been proposed in "Highly insulating aerogel glazing for solar energy use" paper by M. Reim et al in 2001. It is a transparent construction with the 15mm of transparent aerogel material sandwiched in-between two 12mm thick, argon filled layers and two 6mm thick 'kappafloat Pilkington' glass panels (Figure 10). The overall construction has a resulting U-value of $0.446\text{W/m}^2\text{K}$, a solar transmittance of 34% and light transmittance of 47%. The properties of the silica aerogel layer have been assumed and assigned individually based on a prototype construction proposed by "Cabot Corporation" ('Nanogel – translucent aerogel') and include conductivity of 0.018W/mK and light transmittance of approximately 73%. The superinsulated South wall construction is approximately 400mm thick and is consisted, describing from inside to outside, of 25mm thick lightweight plaster, 100mm thick expanded clay concrete block, 110mm of polyurethane insulation board, 50mm of cavity and 105mm of external brickwork. The overall U-value is $0.17\text{W/m}^2\text{K}$.

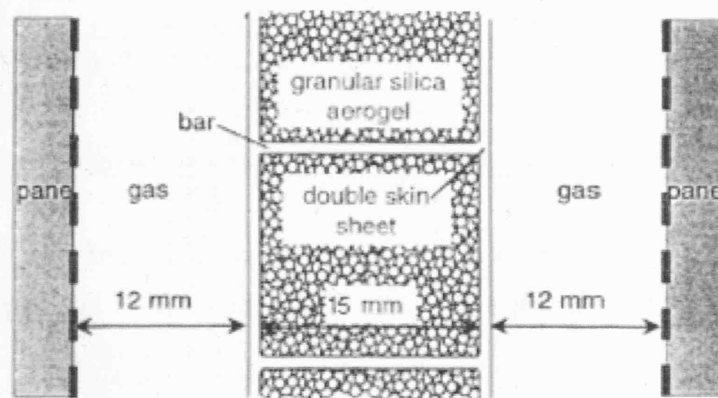


Figure 12. Cut view of the proposed translucent insulation construction. ("Highly Insulating Aerogel Glazing for Solar Energy use", M. Reim et al. 2001)

The remaining parameters of the simulation remain more or less the same as in the nominal building case. Therefore the calendar is broken down into 'weekdays' and 'weekends'; and the weather file selected is "UK_Heathrow_EWY".

The internal conditions selected are again such that represent a basic air conditioned office during weekdays with a schedule set at office hours. Infiltration and ventilation remain the same as

the nominal building case thus they are assumed to be 0.5ACH and 0.8ACH respectively. The lighting gains in this case, however, differ from the nominal building assumptions. It is assumed that since the North façade is fully transparent the lighting demand of the building will be reduced by a half to 6 W/m² instead of 12W/m² that was in the previous case. Occupancy and equipment sensible and latent gains respectively remain as they were assumed in the nominal building case. The thermostat's upper limit is the same at 25°C during the cooling period and the lower at 21°C during the heating period. Tables 7 and 8 illustrate an overview of the assumptions and settings of this particular model case. The weekend internal conditions in this case are no different to the nominal building case. No heating, cooling or ventilation is provided during the weekends and infiltration remains the same as previously at 0.5ACH.

Assumptions – TAS Settings

Internal Conditions	Ventilation	Infiltration	Temperature		Lighting	Occupancy		Equipment	
	0.8 ACH	0.5 ACH	Upper	Lower		Sens.	Lat.	Sens.	Lat.
			25°C	21°C		10W/m ²	5W/m ²	15W/m ²	0W/m ²

Table 7. The assumptions for the internal conditions of the office.

Assumptions – TAS Settings

U-values (W/m ² K)	Walls		Windows	Ground Floor	Roof	Ceilings/Floors
	TIM	Superinsulated				
	0.44	0.17	2.1	0.21	0.26	0.75

Table 8. The assumptions for the U-values of the different building elements of the office.

5.2.5 Case 2: Transparent Insulation on the South Façade of the Building

This case examines the energy performance of the building when transparent insulation construction is applied on the South façade. The North façade is this time superinsulated and the construction parameters, both for the transparent insulation and the superinsulation, remain the same as described in the previous case. Thus, the U-value of the transparent layer is 0.446W/m²K, with a solar transmittance of 34% and a light transmittance of 47% while for the superinsulation the U-value is 0.17W/m²K. The rest of the assumptions and settings of the simulation, such as the calendar and weather files, remain similar to the previous simulations. The internal conditions have not changed either and the gains described for equipment and occupancy remain similar to the case that transparent insulation is applied on the North facade. Lighting energy is set again at 6W/m² based on the same assumption, that lighting demand will be reduced since a transparent

South façade is introduced. All the settings are presented in Tables 9 and 10. Therefore, the only difference in the energy performance of the building in this simulation is a result of the presence of transparent insulation on the South façade.

Assumptions – TAS Settings

Internal Conditions	Ventilation	Infiltration	Temperature		Lighting	Occupancy		Equipment	
	0.8 ACH	0.5 ACH	Upper	Lower	6W/m ²	Sens.	Lat.	Sens.	Lat.
			25°C	21°C		10W/m ²	5W/m ²	15W/m ²	0W/m ²

Table 9. The assumptions for the internal conditions of the office.

Assumptions – TAS Settings

U-values (W/m ² K)	Walls		Windows	Ground Floor	Roof	Ceilings/Floors
	TIM	Superinsulated	2.1	0.21	0.26	0.75
	0.44	0.17				

Table 10. The assumptions for the U-values of the different building elements of the office.

5.2.6 Case 3: Transparent Insulation on 50% of the North Façade of the Building

In this model transparent insulation construction, as described in the previous cases, is applied at the 50% of the North façade's area. The rest of the façade as well as the South elevation are superinsulated with the properties of this construction being similar to the models explained earlier. The weather and calendar data remain fixed as well as the rest of the building elements. The internal conditions parameters are similar to the previous case with the only difference noticed at the lighting gains settings. It is assumed that since 50% of the North façade is transparent the lighting demand will be minimized at list for 30% of the base case. Therefore the lighting gains are assumed to be 9W/m². All the settings are shown on the tables bellow.

Assumptions – TAS Settings

Internal Conditions	Ventilation	Infiltration	Temperature		Lighting	Occupancy		Equipment	
	0.8 ACH	0.5 ACH	Upper	Lower	9W/m ²	Sens.	Lat.	Sens.	Lat.
			25°C	21°C		10W/m ²	5W/m ²	15W/m ²	0W/m ²

Table 11. The assumptions for the internal conditions of the office.

Assumptions – TAS Settings

U-values (W/m ² K)	Walls		Windows	Ground Floor	Roof	Ceilings/Floors
	TIM	Superinsulated	2.1	0.21	0.26	0.75
	0.44	0.17				

Table 12. The assumptions for the U-values of the different building elements of the office.

5.2.7 Case 4: Transparent Insulation on 50% of the South Façade of the Building

This case examines the energy demand of the office building when transparent insulation construction is applied at 50% of the South façade area. Similarly to the third case, the rest of the external walls will be superinsulated. Internal conditions, as well as all the other settings and parameters of the simulation are the same as explained in Case 3. An overview of the assumptions is demonstrated in Tables 13 and 14.

Assumptions – TAS Settings

Internal Conditions	Ventilation	Infiltration	Temperature		Lighting	Occupancy		Equipment	
	0.8 ACH	0.5 ACH	Upper	Lower	9W/m ²	Sens.	Lat.	Sens.	Lat.
			25°C	21°C		10W/m ²	5W/m ²	15W/m ²	0W/m ²

Table 13. The assumptions for the internal conditions of the office.

Assumptions – TAS Settings

U-values (W/m ² K)	Walls		Windows	Ground Floor	Roof	Ceilings/Floors
	TIM	Superinsulated				
	0.44	0.17	2.1	0.21	0.26	0.75

Table 14. The assumptions for the U-values of the different building elements of the office.

5.3 Results

5.3.1 Base Case: The Nominal Building

The results can be analysed, broken down and presented in graphs. For the nominal office the annual energy for heating, cooling and lighting is 43446kWh, 52030kWh and 61374kWh respectively. When these loads are expressed in kWh/m² it is possible to compare the nominal building's energy consumption with the ECON19 (Energy Consumption Guide, Energy use in Offices) benchmark buildings' energy use. The type of building with which the nominal building can be compared to is 'Type 3, Air – Conditioned, standard'. This is largely purpose – built and often speculatively developed. Typical size ranges from 2000m² to 8000m².

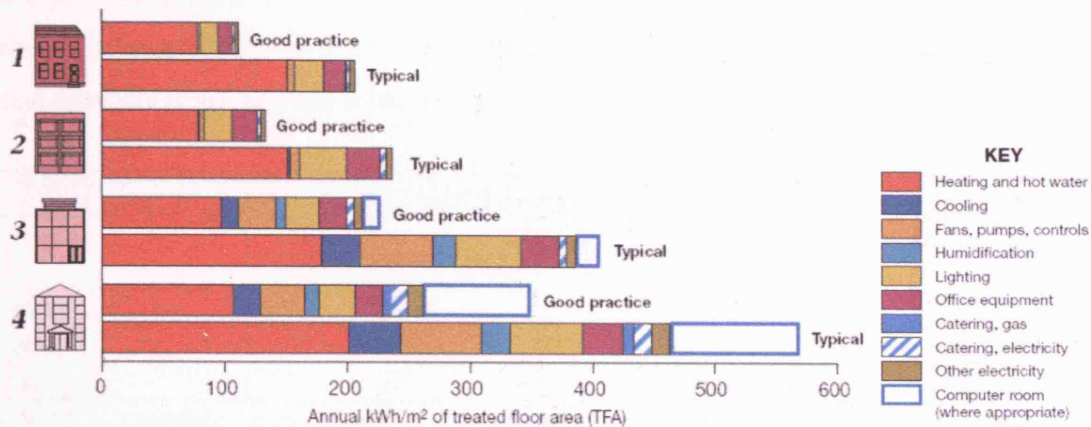
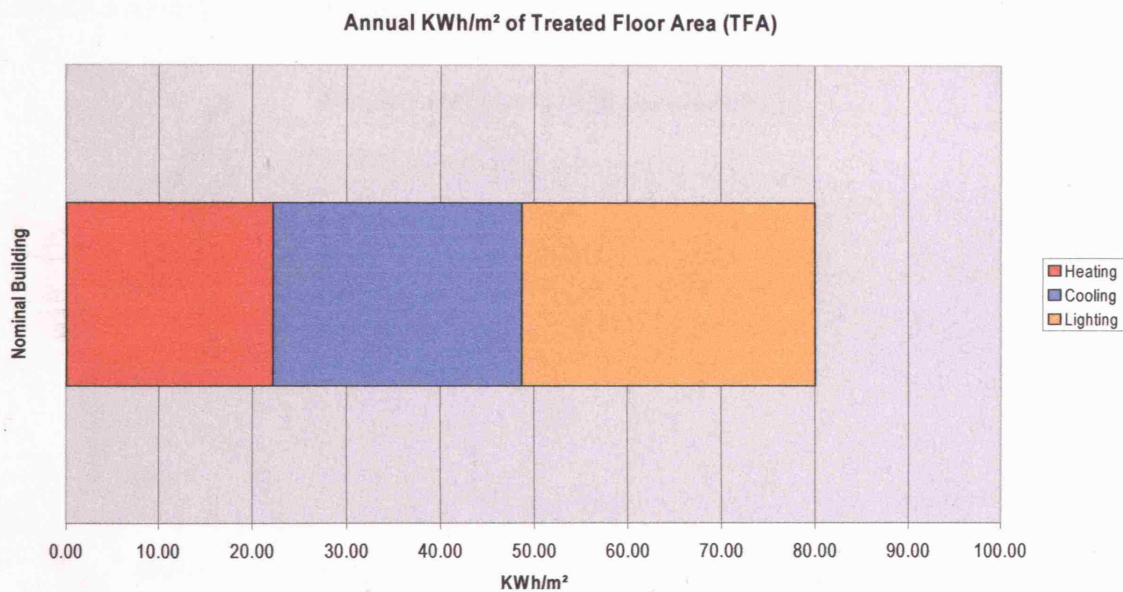


Figure 13. Benchmark values for the annual energy consumption per m² as presented in ECON19.

The nominal building's annual energy consumption per m² of treated floor area is shown at the graph below:



Graph 1. Annual energy demand of the nominal building per m² of treated floor area

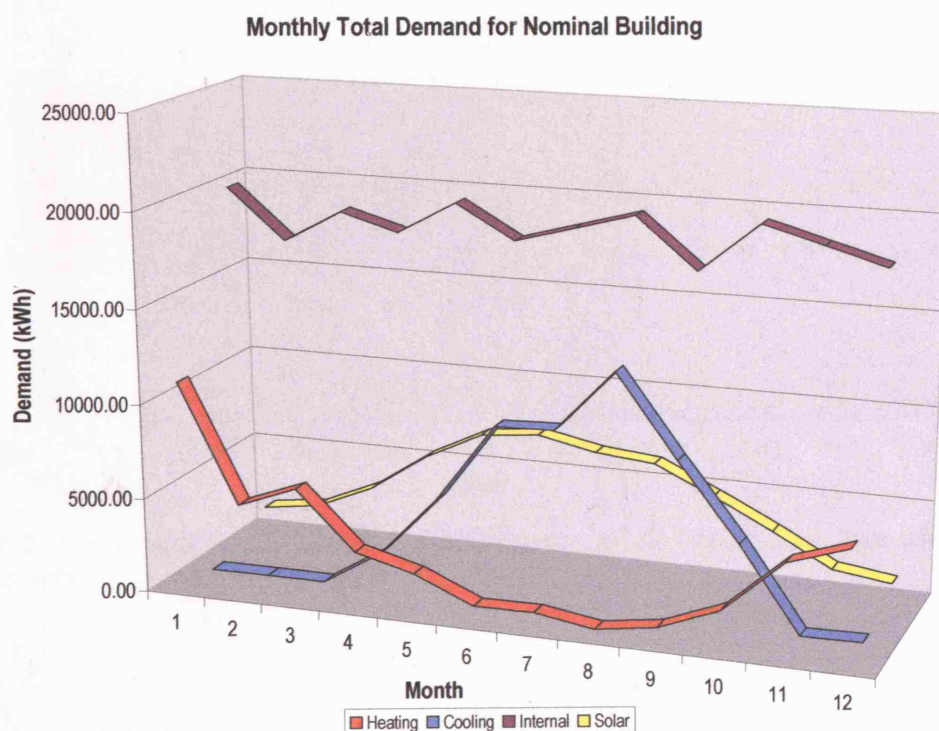
A more detailed comparison of the annual energy consumption values shows that the nominal building has a heating demand much lower than the 'best practice' benchmark value presented by ECON19. This is mostly due to the low U-values used in the construction, but also, because the 'heating' value in ECON19 also represents energy spent to heat water, something that is not the case for the nominal building. Energy use for cooling is a value that falls between the

typical and best practice performance of ECON19 guides while energy demand for lighting is again a value in between the typical and best practice values however, is much closer to the best practice one. A summary of this analysis is presented in Table 5.

Energy Consumption in kWh/m ²			
	ECON19		Nominal Building
	Best Practice Values	Typical Values	
Heating	97	178	22
Cooling	14	31	26.6
Lighting	27	54	31

Table 15. Comparison of the annual energy consumption between the 'Type 3' office building, as presented in ECON19, and the nominal building.

An extensive brake down of the energy consumption into a month-to-month basis in conjunction with the annual solar and internal gains is shown at Graph 2. A total annual overview and brake down of the energy demand is shown in a graph in Appendix 2.

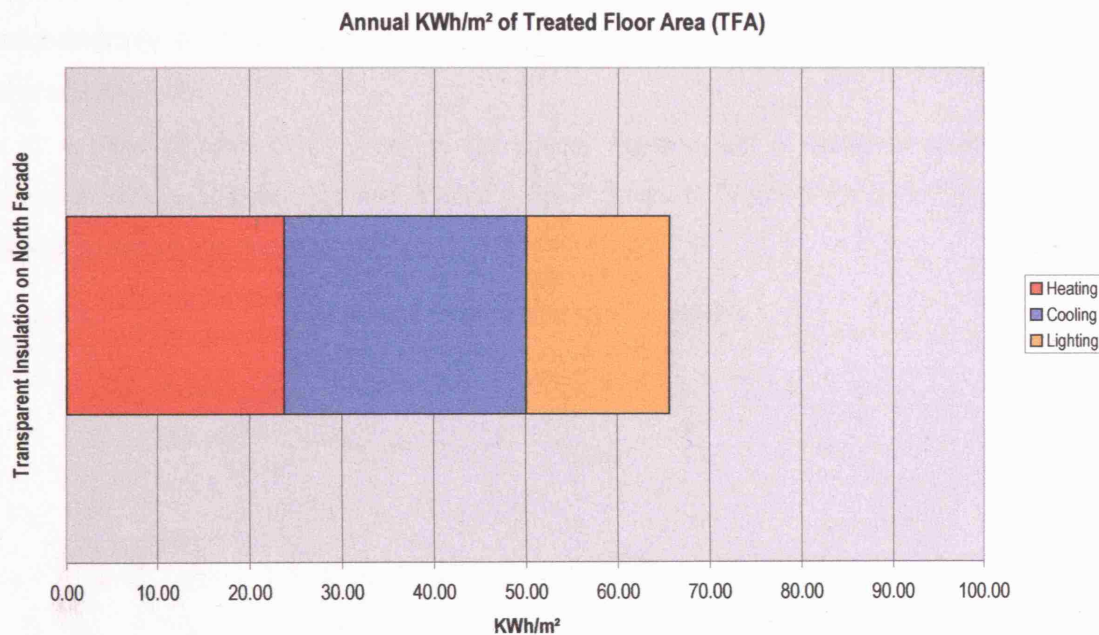


Graph 2. Month to month total energy demand and gains for the nominal building

In terms of internal conditions, as mentioned earlier the cases are fully air – conditioned therefore the conditions are stable and controlled by a thermostat. This situation is repeated in all cases therefore internal temperatures and conditions are not examined. The cases are only examined in terms of energy performance.

5.3.2 Case 1: Transparent Insulation on the North Façade of the Building

Similarly to the first case, after running the simulation in TAS it is possible to analyse the energy performance of the building and compare it with the ECON19 benchmarks. The annual energy demand per m^2 can be broken down again into three categories – heating, cooling and lighting – and is illustrated in Graph 3.



Graph 3. Annual energy demand of the building per m^2 of treated floor area when there is transparent insulation construction on the North façade.

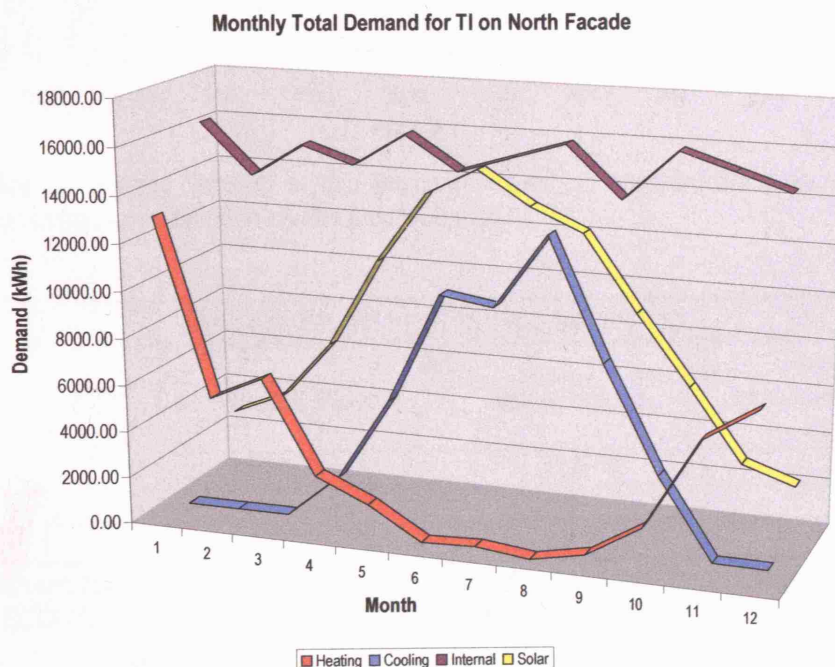
A more analytical comparison between this case and ECON19 is demonstrated in Table 6.

Energy Consumption in kWh/m ²			
	ECON19		Transparent Insulation on North facade
	Best Practice Values	Typical Values	
Heating	97	178	23.6
Cooling	14	31	26.3
Lighting	27	54	15.6

Table 16. Comparison of the annual energy consumption between the 'Type 3' office building, as presented in ECON19, and the building with transparent insulation on the North façade.

In the same way to the nominal building case, the annual energy spent for heating is much lower from the best practice and typical values shown in ECON19. Cooling energy is again in-between the best practice and typical values. Using transparent insulation construction resulted to a noticeable reduction of the energy spent for lighting down to 15.6kWh/m², which is well below the best practice values.

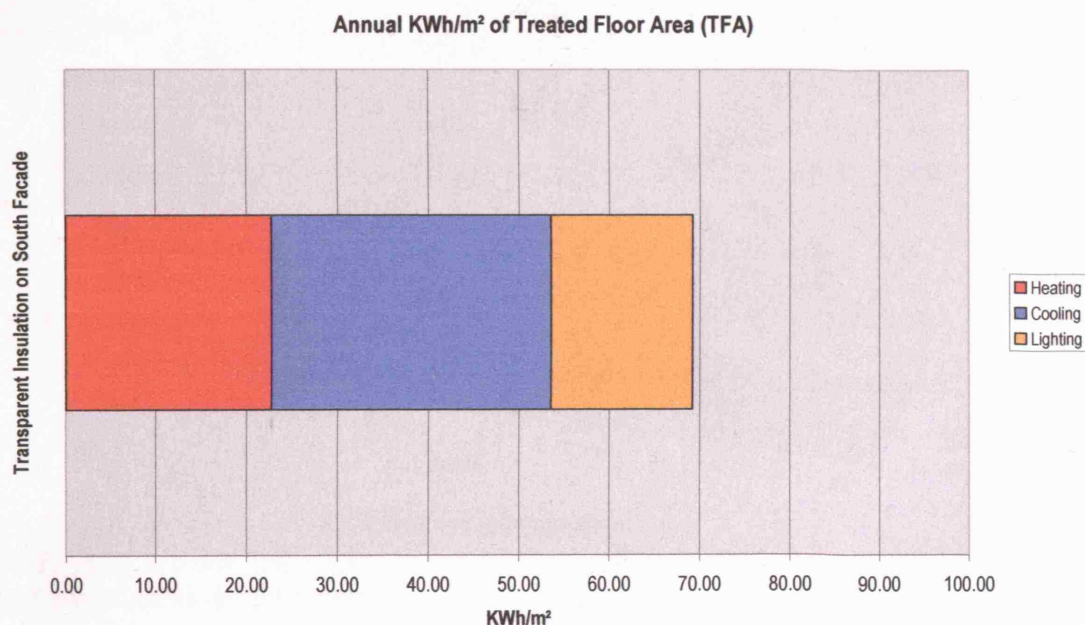
A more detailed break down of the energy demand into a month-to-month basis in conjunction with the annual solar and internal gains is shown at Graph 4. An annual graph of the total energy demand is shown in the Appendices' section 3.



Graph 4. Month to month total energy demand and gains for the building when transparent aerogel is used on the North façade.

5.3.3 Case 2: Transparent Insulation on the South Façade of the Building

In this case, after running the simulation, the energy demand for heating, cooling and lighting is 44462kWh, 60451kWh and 30687kWh respectively. As demonstrated in the previous case these results can be translated in kWh/m² and compared with ECON19 typical and best practice values. A representation of these results is shown in Graph 5, while a much clearer comparison is shown in Table 17.



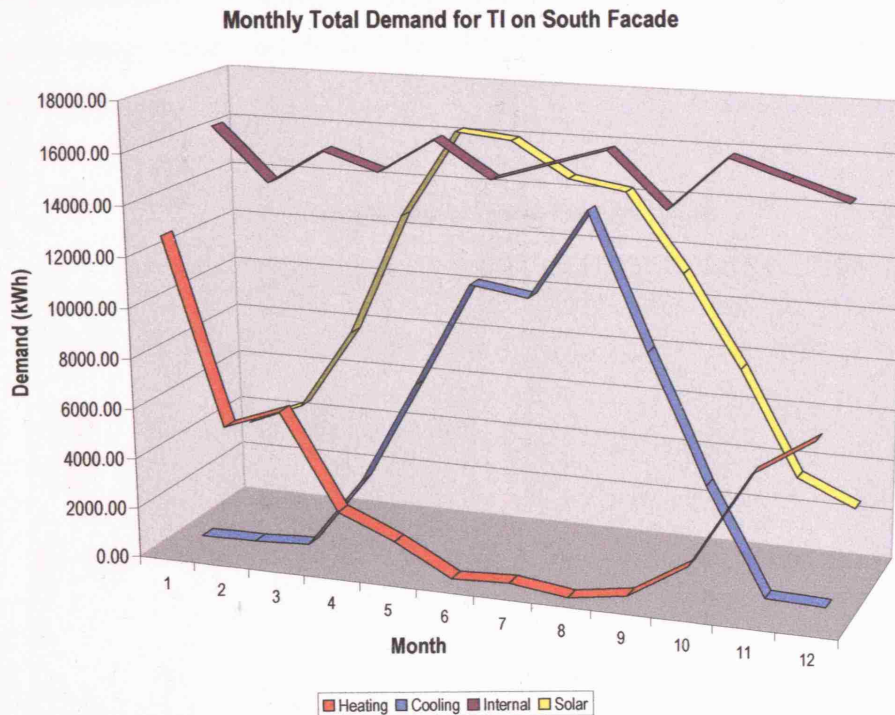
Graph 5. Annual energy demand of the building per m² of treated floor area when there is transparent insulation construction on the South façade.

Energy Consumption in kWh/m ²			
	ECON19		Transparent Insulation on South facade
	Best Practice Values	Typical Values	
Heating	97	178	22.7
Cooling	14	31	31
Lighting	27	54	15.6

Table 17. Comparison of the annual energy consumption between the 'Type 3' office building, as presented in ECON19, and the building with transparent insulation on the South façade.

A month-to-month analysis shows that the solar gains are higher than the previous cases and that there is a slight decrease in energy demand for heating however; there is a significant

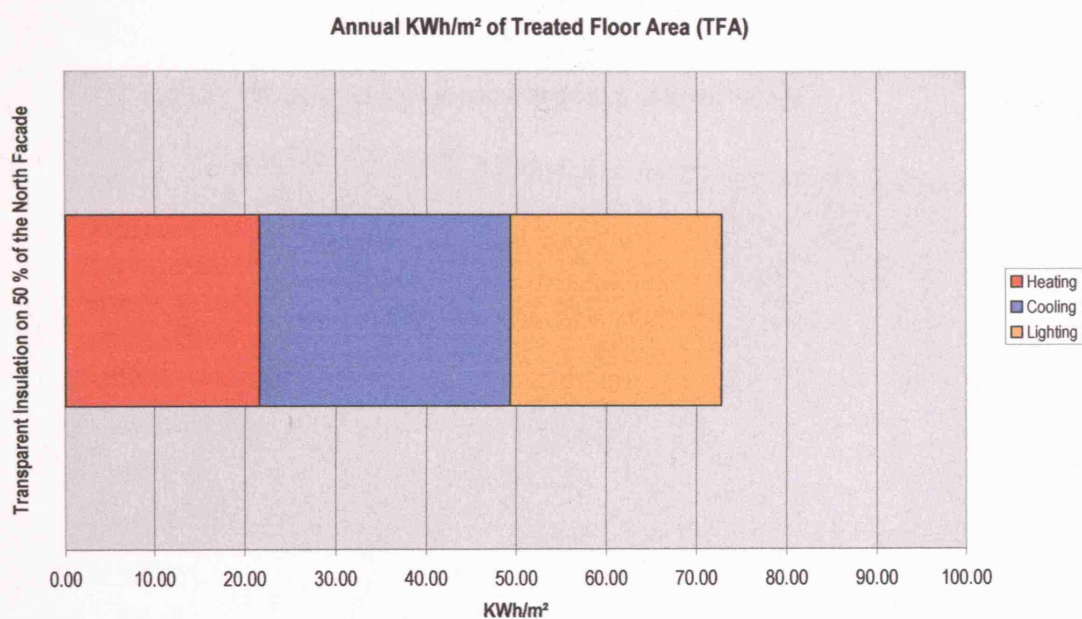
increase in the cooling demand mainly caused by the high solar gains (Graph 6). The cooling values now are equal to the typical values described in ECON19. A graph with the total annual energy demand is illustrated in Appendix 4.



Graph 6. Month to month total energy demand and gains for the building when transparent aerogel is used on the South façade.

5.3.4 Case 3: Transparent Insulation on 50% of the North Façade of the Building

The simulation of this model case also resulted in some useful information. The energy demand is 42282.6kWh for heating, 54289.5kWh for cooling and 46031kWh for lighting. A graph showing the energy breakdown in kWh/m² similarly to the way it is being described in ECON19 is illustrated bellow.



Graph 7. Annual energy demand of the building per m² of treated floor area when there is transparent insulation construction on 50% of the North façade.

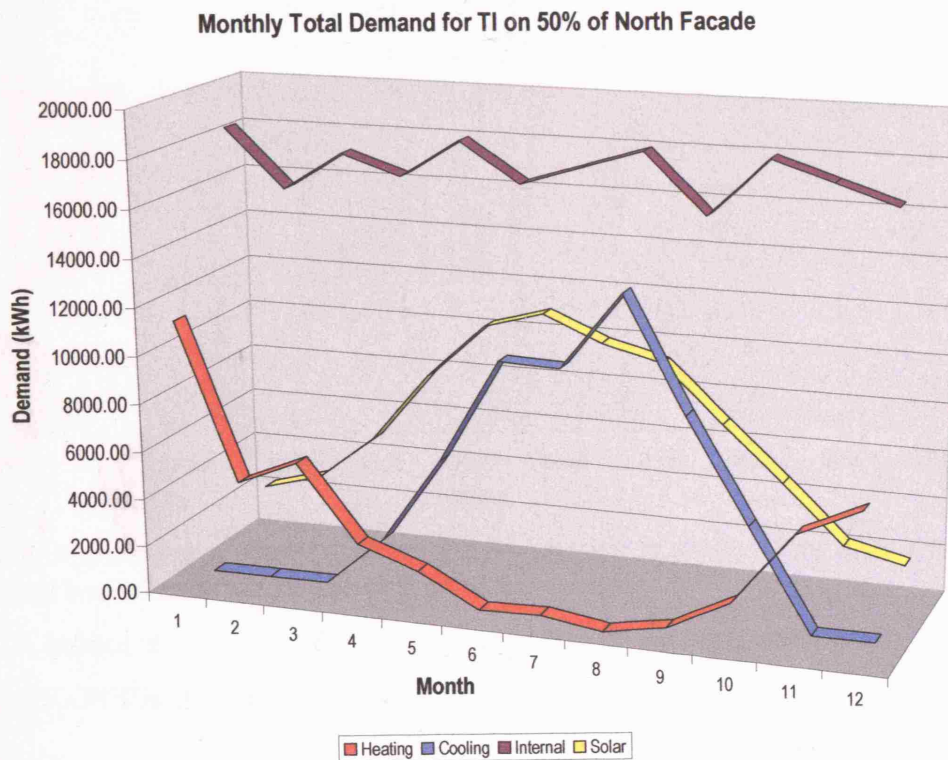
A more analytical table shows the exact relationship of this model case with the benchmark values that are described in ECON19.

Energy Consumption in kWh/m ²			
	ECON19		Transparent Insulation on 50% of the North facade
	Best Practice Values	Typical Values	
Heating	97	178	21.6
Cooling	14	31	27.7
Lighting	27	54	23.5

Table 18. Comparison of the annual energy consumption between the 'Type 3' office building, as presented in ECON19, and the building with transparent insulation on 50% of the North façade

In this case the heating values are again considerably low in comparison to typical and best practice values. As mentioned previously this is due to the lack of information on energy spent for heating water. Cooling value is very close to typical benchmarks however, it is higher than the Base Case and Case 1, which were described previously. Lighting energy demand is lower than the best practice value but higher than the resulting one for Case 1.

A monthly breakdown of the energy demand is demonstrated at the following graph. An overall picture of the total energy demand is shown in Appendix 5.

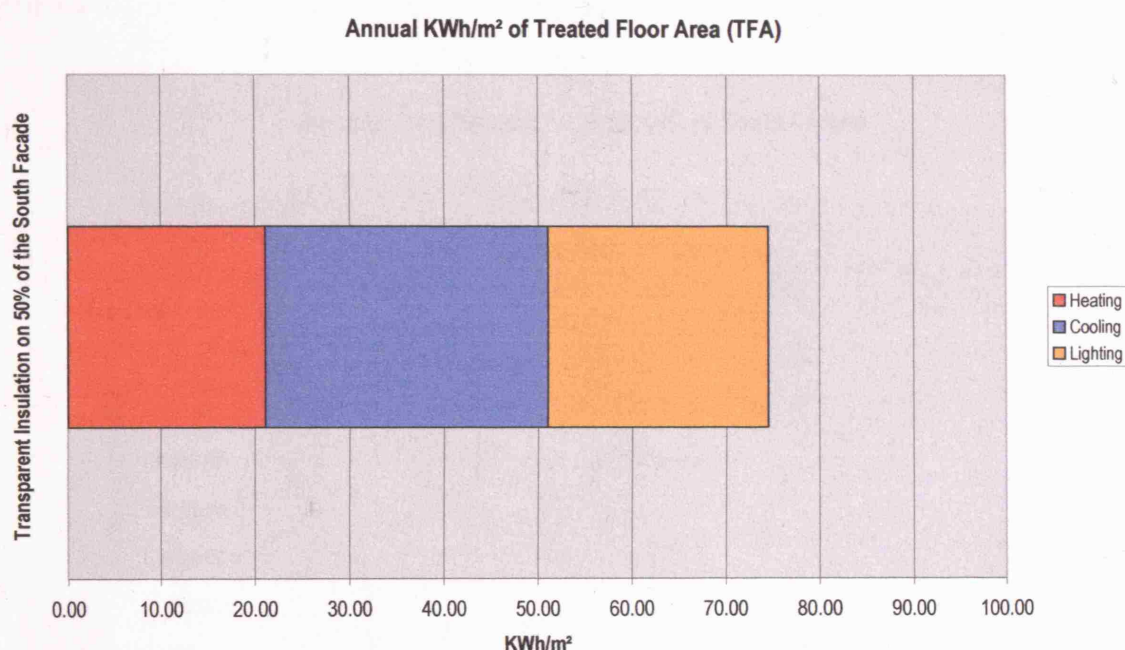


Graph 8. Month to month total energy demand and gains for the building when transparent aerogel is used on 50% of the North façade.

The thermal performance of the building is not any different from the other cases studied above, since it is fixed with a thermostat.

5.3.5 Case 4: Transparent Insulation on 50% of the South Façade of the Building

In this occasion transparent insulation is applied on the 50% of the South façade. The energy demand is 41307kWh, 58624.5kWh and 460431kWh for heating, cooling and lighting respectively. The annual kWh/m² is shown in the graph bellow.



Graph 9. Annual energy demand of the building per m² of treated floor area when there is transparent insulation construction on 50% of the South façade.

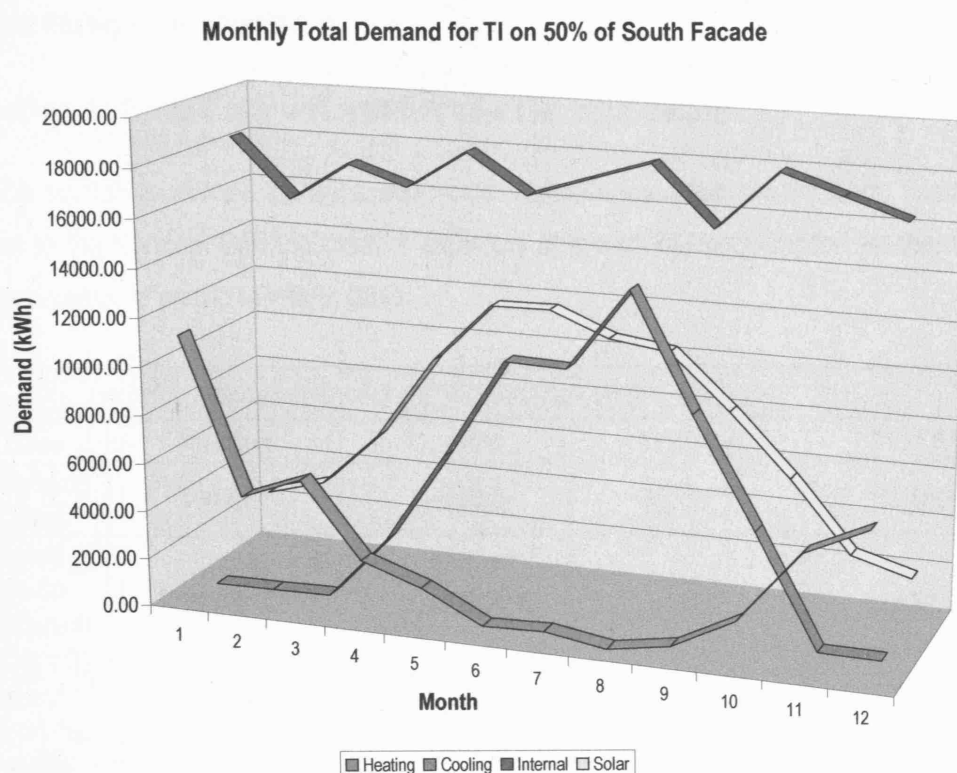
A detailed analysis of the energy consumption beside the best practice and typical values shown in ECON19 is demonstrated in Table 19.

Energy Consumption in kWh/m ²			
	ECON19		Transparent Insulation on 50% of the South facade
	Best Practice Values	Typical Values	
Heating	97	178	21
Cooling	14	31	31
Lighting	27	54	23.5

Table 19. Comparison of the annual energy consumption between the 'Type 3' office building, as presented in ECON19, and the building with transparent insulation on 50% of the South façade

The simulation shows that the heating demand has decreased slightly compare to the previous case. The cooling load has significantly risen and this is mainly to the high solar gains, however the value remains within the typical value proposed in the ECON19 guide. The energy consumed for lighting is again lower than the Base Case and than the best practice value.

Similarly to the previous cases the month-to-month energy consumption is demonstrated in the graph below. Information on the overall energy performance of this case model is included in Appendix 6.



Graph 8. Month to month total energy demand and gains for the building when transparent aerogel is used on 50% of the South façade

5.4 Result Overview

The previous chapters examined the simulation results individually for every model case. However, a more important and interesting way of approaching the results is by looking at the different model cases comparatively therefore, the analysis will be split – up into two sections. The first section is a comparison between the Base Case and the various applications of transparent insulation on the North façade, and secondly, between the Base Case and the various applications on the South façade. Each case will be focused on the energy consumption of the building and will try to answer the aims set in this thesis.

5.4.1 Section 1: Base Case – North Façade TIM application

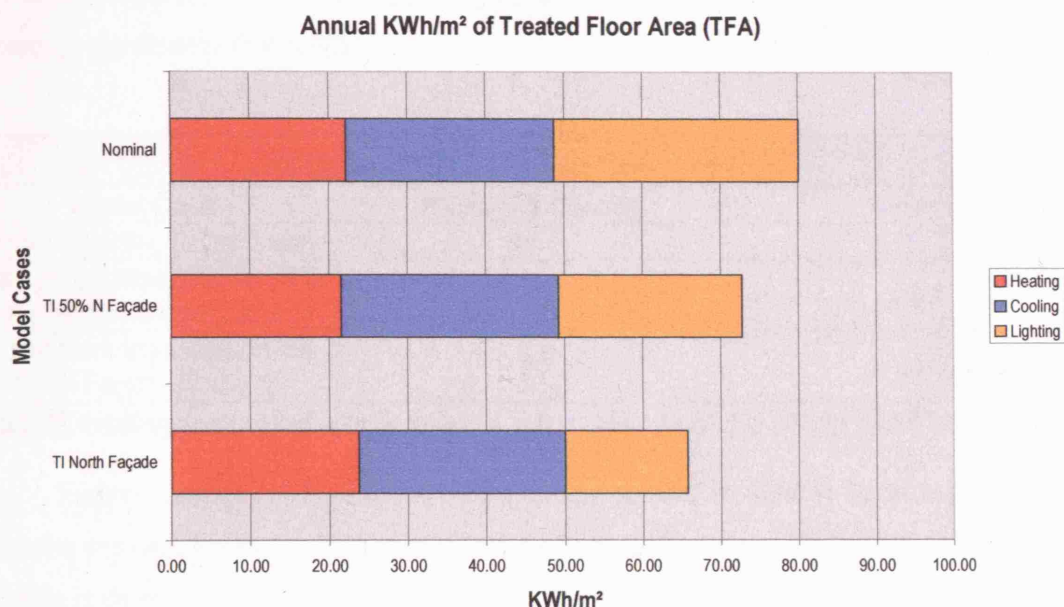
This section examines the application of transparent insulation on the North Facades in comparison to the Nominal Building case. A summary of the energy consumption for these three cases is demonstrated on the following table.

Annual Energy Consumption (kWh)				
Model Case	Heating	Cooling	Lighting	TOTAL
Nominal Building (Base Case)	43445.7	52030.3	61374.7	156850.7
Transparent Insulation on 50% of the North Façade (Case 3)	42282.6	54289.4	46031	142603
Transparent Insulation on the North Façade (Case 1)	46415.8	51642.2	30687.3	128745.4

Table 20. Comparative annual energy consumption between the Base Case and the North façade's TIM applications.

A first conclusion after analyzing the table above is that the total energy demand decreases as the amount of transparent insulation on the North façade increases. This is mainly to the energy used for lighting the building. Heating and cooling seem to consume roughly similar amounts of energy through out the different cases however; a more detailed examination is necessary in order to have safer conclusions. A second stage of the analysis would be to transform

each case's energy consumption into kWh/m². A synopsis of this step is shown in Graph 9 and Table 21.



Graph 10. Annual energy consumption per m² break – down for each of the examined cases.

Annual kWh/m ² of Treated Floor Area				
Model Case	Heating	Cooling	Lighting	TOTAL
Nominal Building (Base Case)	22.17	26.55	31.32	80.04
Transparent Insulation on 50% of the North Façade (Case 3)	21.6	27.7	23.5	72.8
Transparent Insulation on the North Façade (Case 1)	23.7	26.35	15.66	65.7

Table 21. The annual kWh/m² of Treated Floor Area for the three case models.

Studying the above graph and table, it is interesting that lighting appears to be an important energy factor. The nominal office case is based on the current Building Regulations; and as a building is quite tightly constructed. This makes lighting a comparable value to the energy spent for cooling and heating. It is possible that in the future the introduction of stricter Building Regulations will result further reductions in heating and cooling demand, thus lighting will be a

major energy contributor. Therefore, controlling the lighting energy and minimizing it at the same time seems to be an important field of study, in which transparent insulation will have a significant role. In all three cases heating and cooling appear to be approximately 50kWh/m², while lighting decreases significantly (Table 22).

Annual Energy Demand (kWh/m²)		
Model Case	Heating & Cooling	Lighting
Nominal Building (Base Case)	48.7	31.3
Transparent Insulation on 50% of the North Façade (Case 3)	49.3	23.5
Transparent Insulation on the North Façade (Case 1)	50	15.6

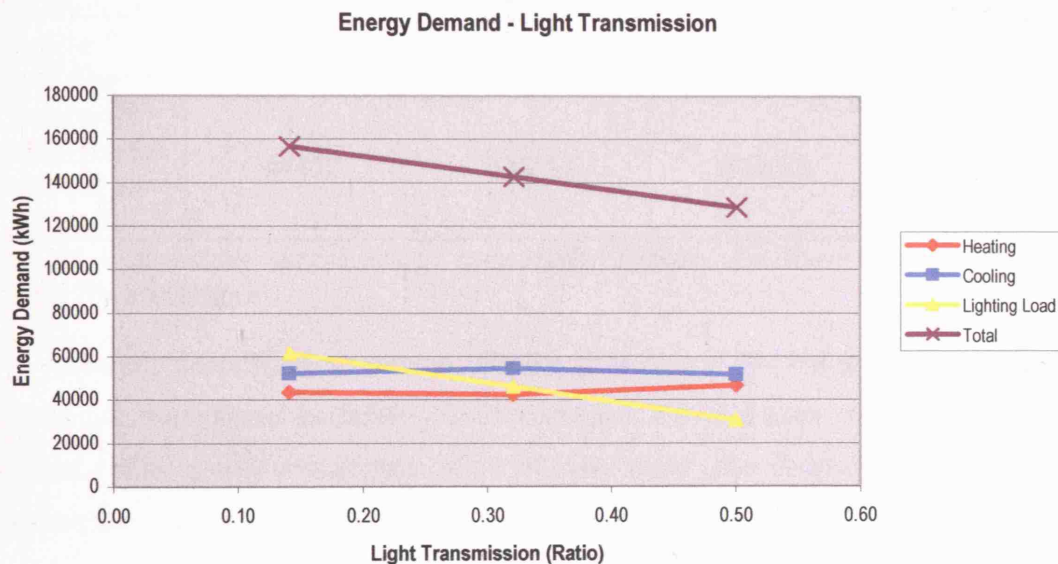
Table 22. Heating and cooling energy demand in comparison with the energy spent for lighting.

Further analysis can be focused on the energy demand for lighting. In the examined three cases the assumptions for the lighting load, as well as the link between the opaque and transparent surfaces is demonstrated in Table 23. Additionally, this table shows a light transmission ratio for each individual case. This value is a result of a simple calculation. The light parameters of each construction method applied on the building's elements are known due to the use of TAS. Thus, for the transparent insulation construction the light transmission is 0.47 while for windows is 0.74 and for opaque construction 0. Knowing the overall area of the façade as well as the individual area of each construction it is simple to calculate the average transmission for each model case. The relationship between light transmission and energy performance is an interesting part of the analysis.

Design Parameters-Assumptions					
Model Case	Lighting (w/m²)	Glazed Area (m²)	TIM Area (m²)	Opaque Area (m²)	Light Transmission (Ratio)
Nominal Building (Base Case)	12	18.2	0	77.73	0.14
Transparent Insulation on 50% of the North Façade (Case 3)	9	18.2	36.72	41.01	0.32
Transparent Insulation on the North Façade (Case 1)	6	18.2	73.43	4.30	0.5

Table 23. Assumptions and design parameters of the three case models.

Studying Graph 11 one can see that energy use for lighting has a linear relationship with the light transmission. As transmission rises, demand for lighting decreases – something that explains why transparent insulation can be a very interesting material to use in office type buildings. Further examination of this graph shows that the energy for cooling and heating in the case of maximum transmission is similar to the base case (i.e. when opaque materials are used). This means that the thermal properties of transparent insulation are exceptional, and with future improvement as a material it could perform even better. Total energy demand also appears to have a linear relationship with light transmission – illustrating that transparency does not necessarily means additional energy consumption.



Graph 11. The relationship between energy demand and light transmission.

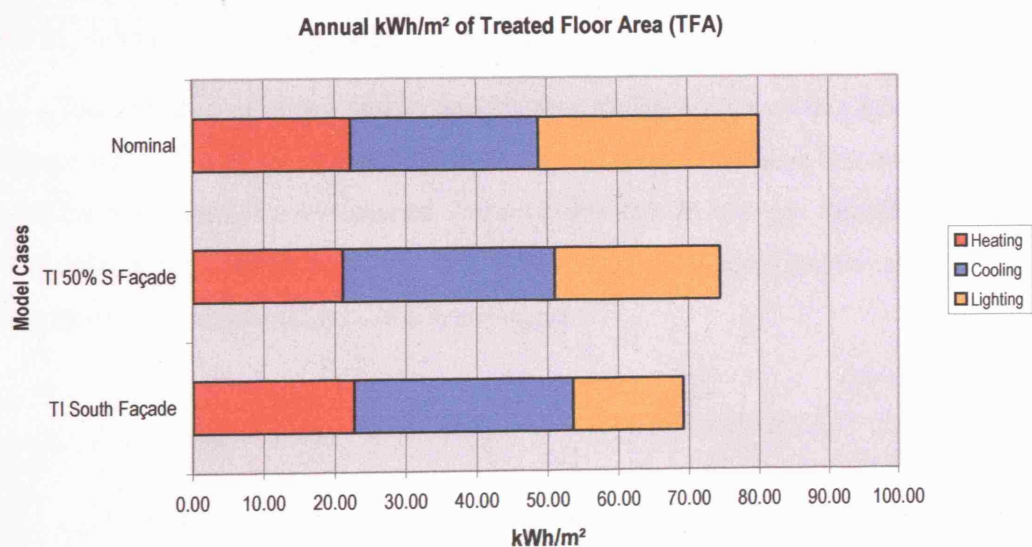
5.4.2 Section 2: Base case – South Façade TIM application

In a similar way to the previous stage, this section examines the relationship between the Base Case and the application of TIM on the South façade in terms of energy performance. The annual energy consumption for each model case is summarized in the following table.

Annual Energy Consumption (kWh)				
Model Case	Heating	Cooling	Lighting	TOTAL
Nominal Building (Base Case)	43445.7	52030.3	61374.7	156850.7
Transparent Insulation on 50% of the South Façade (Case 4)	41307.2	58624.5	46031	145962.7
Transparent Insulation on the South Façade (Case 2)	44462	60451.6	30687.3	135601

Table 24. Comparative annual energy consumption between the Base Case and the North façade's TIM applications.

Studying the table above it seems that the application of TIM has a positive result on the total energy consumption of the building, which decreases. A second stage of the analysis can be a comparison of the energy consumption per m² for every model case (Graph 12). That would give a clearer picture of the impact that TIM has on the overall energy consumption.



Graph 12. Annual energy consumption per m² break – down for each of the examined cases.

Annual kWh/m² of Treated Floor Area				
Model Case	Heating	Cooling	Lighting	TOTAL
Nominal Building (Base Case)	22.17	26.55	31.32	80.04
Transparent Insulation on 50% of the South Façade (Case 4)	21	30	23.5	74.5
Transparent Insulation on the South Façade (Case 2)	22.7	30.9	15.6	69.2

Table 25. The annual kWh/m² of Treated Floor Area for the three case models.

Similarly to the first section, lighting seems to be an influencing factor for minimizing the overall energy demand of the building. Energy consumption for heating and cooling in this section seems to be slightly higher than the North façade TIM application; however it is still around 50 kWh/m².

Annual Energy Demand (kWh/m²)		
Model Case	Heating & Cooling	Lighting
Nominal Building (Base Case)	48.7	31.3
Transparent Insulation on 50% of the North Façade (Case 3)	51	23.5
Transparent Insulation on the North Façade (Case 1)	53.5	15.6

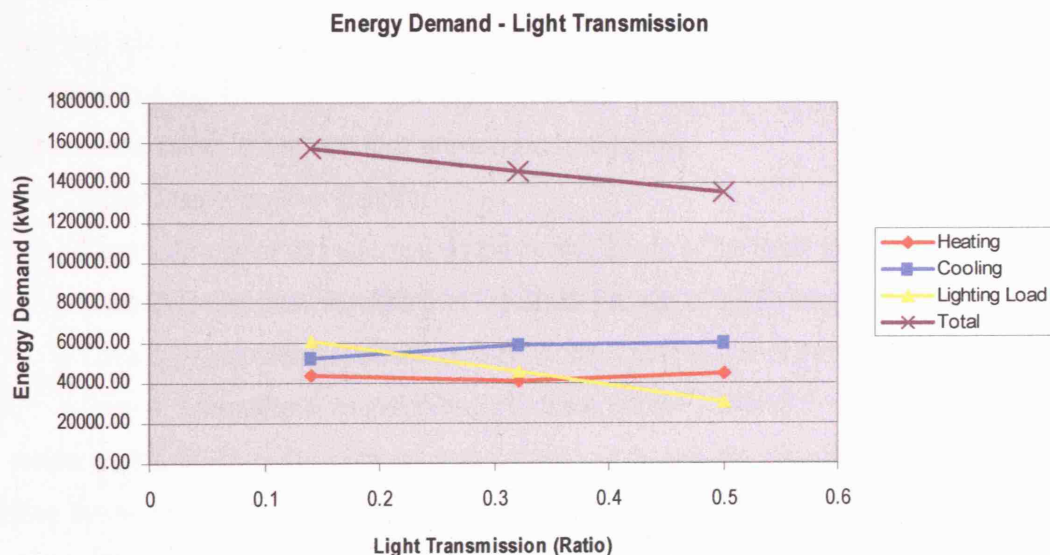
Table 26. Heating and cooling energy demand in comparison with the energy spent for lighting.

The examination of the results can be now focused more on the lighting energy in an analogous way to the previous case. Therefore the relationship between the energy demand and the light transmission will be investigated. The light transmission is a ratio calculated with the same method described in Section 1. A summary of the design parameters and the assumptions made in each model case are described in the following table.

Design Parameters-Assumptions					
Model Case	Lighting (w/m ²)	Glazed Area (m ²)	TIM Area (m ²)	Opaque Area (m ²)	Light Transmission (Ratio)
Nominal Building (Base Case)	12	18.2	0	77.73	0.14
Transparent Insulation on 50% of the South Façade (Case 4)	9	18.2	36.72	41.01	0.32
Transparent Insulation on the South Façade (Case 2)	6	18.2	73.43	4.30	0.5

Table 27. Assumptions and design parameters of the three case models.

The following graph shows that in the case of TIM application on the South façade, lighting decreases in a reciprocal relationship to the light transmission ratio. At the same time, cooling seems to increase significantly, while heating demand slightly rises as well. However, the overall energy demand decreases considerably, showing that transparency is not necessarily a negative condition. Transparent insulation materials with the exceptional thermal and transmission parameters seem to be ideal for future use in office buildings.



Graph 13. The relationship between energy demand and light transmission.

6. Conclusion

A large amount of the World's energy is spent on heating, cooling and lighting of the buildings. This energy consumption leads to considerable amount of CO₂ emissions, which contributes to global warming. Current architectural trends encourage the use of glazed facades and large glazing surfaces mainly in office buildings. These design elements relate closely to the energy performance of a building and promote the use of air – conditioning systems that contribute to CO₂ emissions. The need of an improved energy performance of the buildings has resulted in stricter Building Regulations, which promote the improvement of the environmental performance of buildings. Therefore, there is a balance that architects need to keep between their design decisions and Building Regulations' energy requirements. New materials and technologies, mainly in the glazing industry, are brought up in order to meet both architectural and Building Regulations' needs. Transparent insulation (TIMs) is part of this new class of materials and has a large potential to be used for improving a building's energy performance. This dissertation looked on the potential that transparent insulation materials could have when used as facade materials in an office building in UK. The method followed was based on computational dynamic simulations and result comparisons. Firstly, an office building based on the current Building Regulations (Base Case) was formed; and after studying its energy performance it was compared with alternative model – cases of the same building type, yet with transparent insulation applied in the different facades. There were five model cases in total and they are summarized bellow:

- Base Case – Nominal Building
- Case 1: Transparent Insulation on the North Façade of the Building
- Case 2: Transparent Insulation on the South Façade of the Building
- Case 3: Transparent Insulation on 50% of the North Façade of the Building
- Case 4: Transparent Insulation on 50% of the South Façade of the Building

A review of the Building Regulations was carried out before the simulation stage in order to achieve the environmental requirements of the Base Case. A theoretical appraisal of Transparent Insulation Materials was also conducted in order to understand the way that they can be used in buildings as well as the different performance parameters and characteristics that they may have.

The simulations stage was performed using TAS, a computer simulation program and Excel spreadsheets. For this stage several TAS parameters were selected to be similar through out

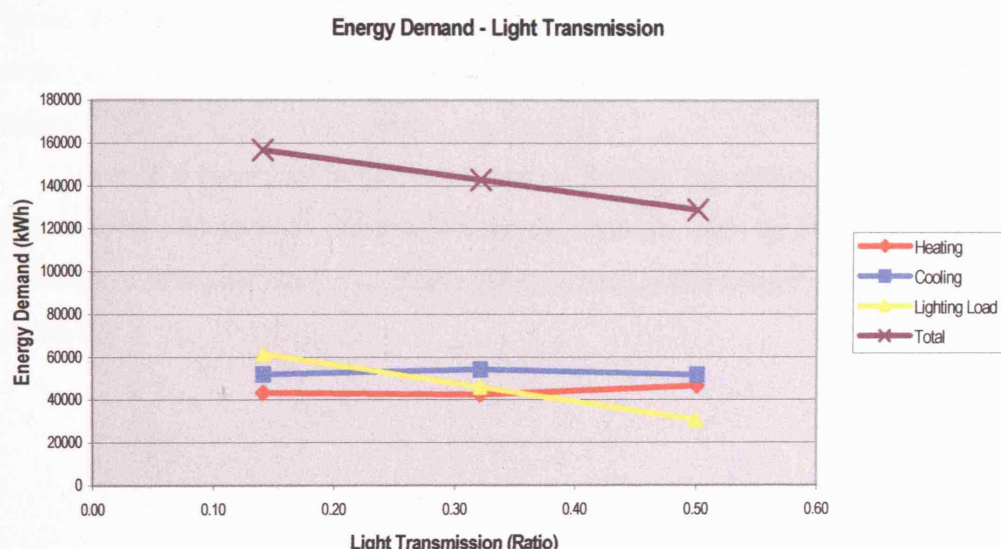
the simulations in order for the examination to be focused on the performance of transparent insulation. Thus, the weather files, calendar type, constructions and internal conditions are similar in each case apart from the transparent insulation and the superinsulation constructions applied. Cases 1 - 4 focused on the application of transparent insulation in the South/North facades and the rest of the building elements were superinsulated. A major assumption and variation between the models was the fact that the lighting gain would change from case to case since different transparencies were achieved. Thus for the Base Case a 12W/m^2 was assumed while for North/South Cases the lighting load assumed to be cut in half. The 50% Cases simulated an assumed lighting load of 9W/m^2 .

Summary of annual kWh/m² of Treated Floor Area				
Model Case	Heating	Cooling	Lighting	TOTAL
Nominal Building (Base Case)	22.17	26.55	31.32	80.04
Transparent Insulation on the North Façade (Case 1)	23.7	26.35	15.66	65.7
Transparent Insulation on the South Façade (Case 2)	22.7	20.9	15.66	69.2
Transparent Insulation on 50% of the North Façade (Case 3)	21.6	27.7	23.5	72.8
Transparent Insulation on the 50% of the South Façade (Case 4)	21	30	23.5	74.5

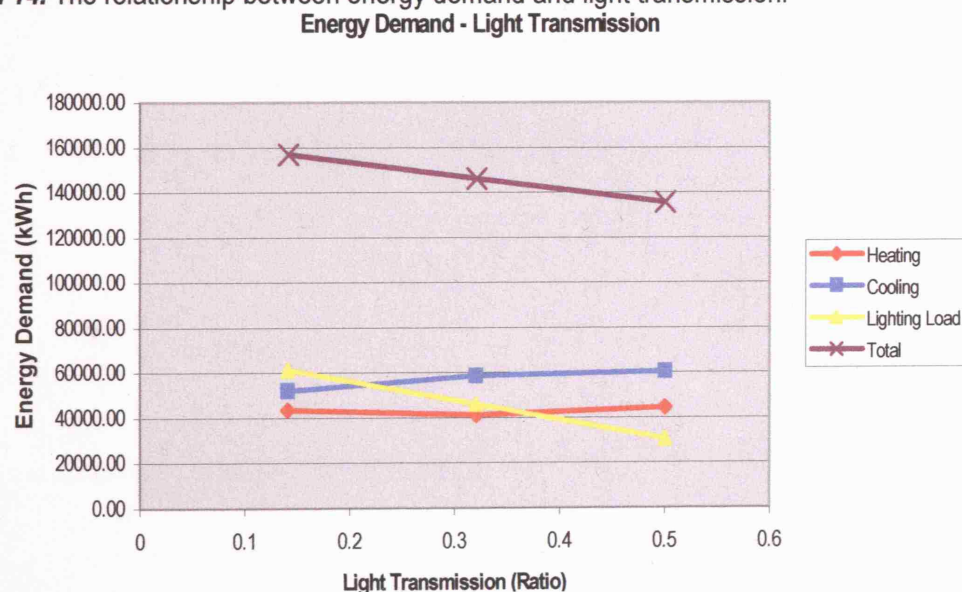
Table 28. Summary of annual kWh/m² of Treated Floor Area.

A summary of the results of each case (Table 28) shows that generally the application of transparent insulation materials improves the energy performance of the building. It seems that the 50% applications improve the energy performance of the building however when a façade is totally covered with TIMs the benefit is even larger. All of these cases were compared to the proposed typical and best practice values of a benchmark office type building in ECON19 and showed that

the energy consumed in most of the cases is less than it. Therefore transparent insulation seems to be an excellent material that architects could use in the future in order to achieve transparency and similarly their thermal and lighting performance is welcomed by the Building Regulations. The most successful application was the one with transparent insulation materials on the North façade (Case 1). A more detailed analysis looks in the relationship of the average transmission of each case and the overall energy saving. This study illustrated that the extensive rise of the transmission does not affect negatively the energy performance, yet in the South Façade applications there were some increases in the energy for cooling and heating (Graphs 14 and 15).



Graph 14. The relationship between energy demand and light transmission.



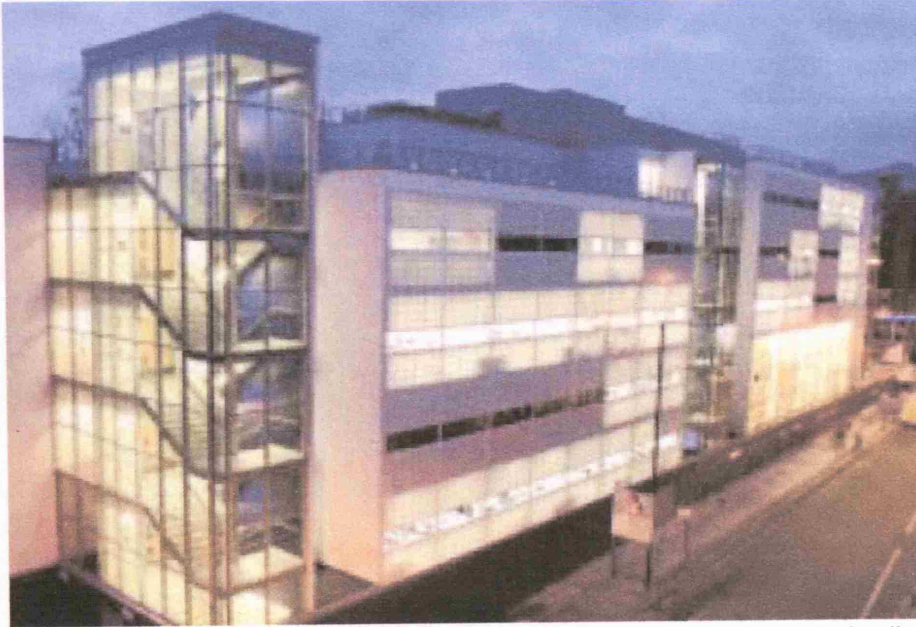
Graph 15. The relationship between energy demand and light transmission.

Finally it should be noted that this dissertation looks only at a small field of the possibilities that TIMs can have when used at an office type building. A future analysis could be focused on the performance and use of transparent insulation in a domestic scale and perhaps how would TIMs perform in other climates than the UK one. Furthermore, a cost analysis comparing TIMs to other materials and environmental design methods or systems (for example PVs) could be carried out; however the lack of information on the prices of TIMs did not allow this type of study. It should be noted that TIMs are mostly at an experimental level; therefore the individual companies that try to produce the cheapest prototype and at the same time compete each other protect any information on prices. Several scientific studies are currently under way in order to improve the transparent and thermal qualities of transparent insulation, thus in the future better performances should be expected.

There is a belief that in the future, stricter Building Regulations will limit the architects' design decisions, however the introduction of new materials, such as TIMs, in the world market help designers to achieve their imaginative plans without jeopardizing the energy performance of the building.

Appendices

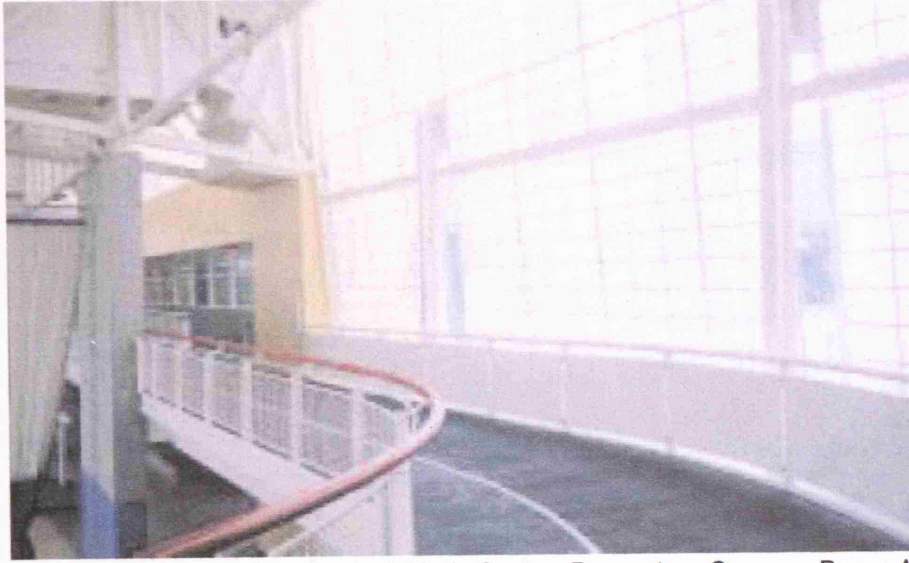
Examples of buildings which use TIMs as Façade elements



City and Inslington College, London, UK –Deveraux Architects (www.kalwall.com)



Ahwatukee Foothills Family YMCA, Phoenix, Arizona –Architekton Architects
(www.kalwall.com)



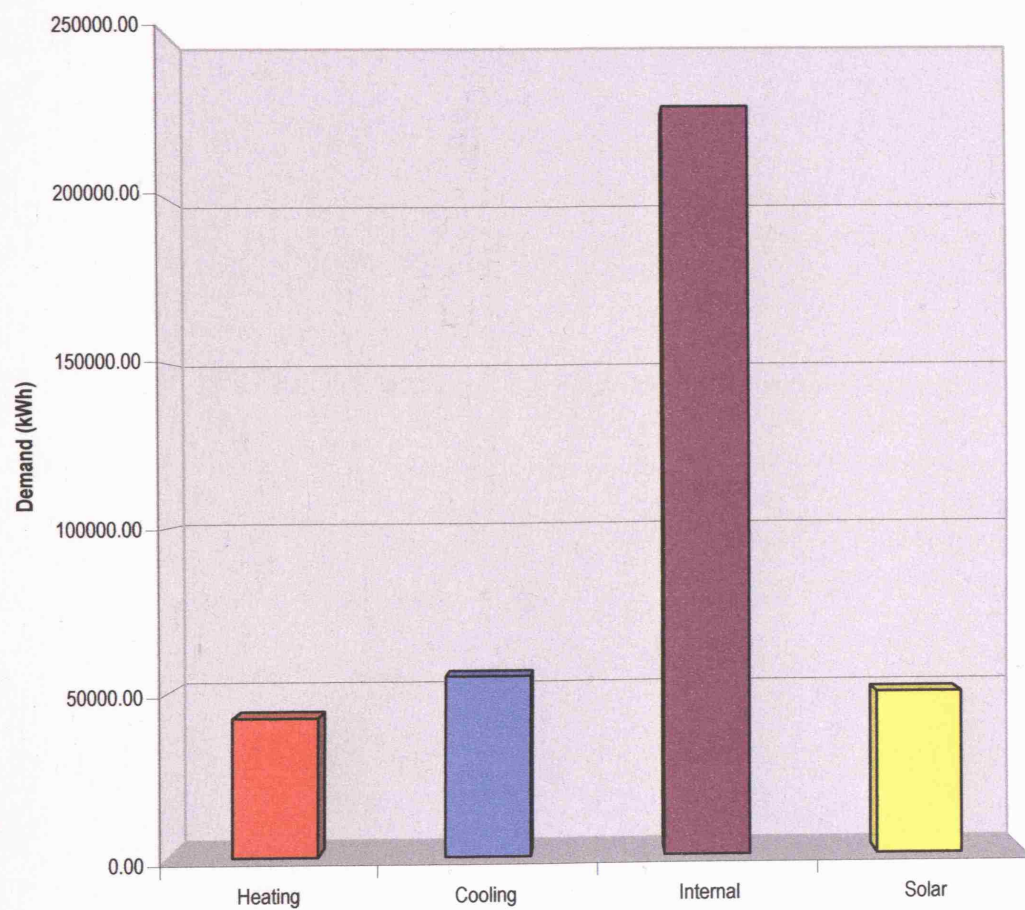
Tualatin Hills Park & Recreation Sports Athletic Centre, Beaverton, Oregon –Boora Architects
(www.kalwall.com)



Knox County Health Department, Mt. Vernon, Ohio –Maley Architecture Group
(www.kalwall.com)

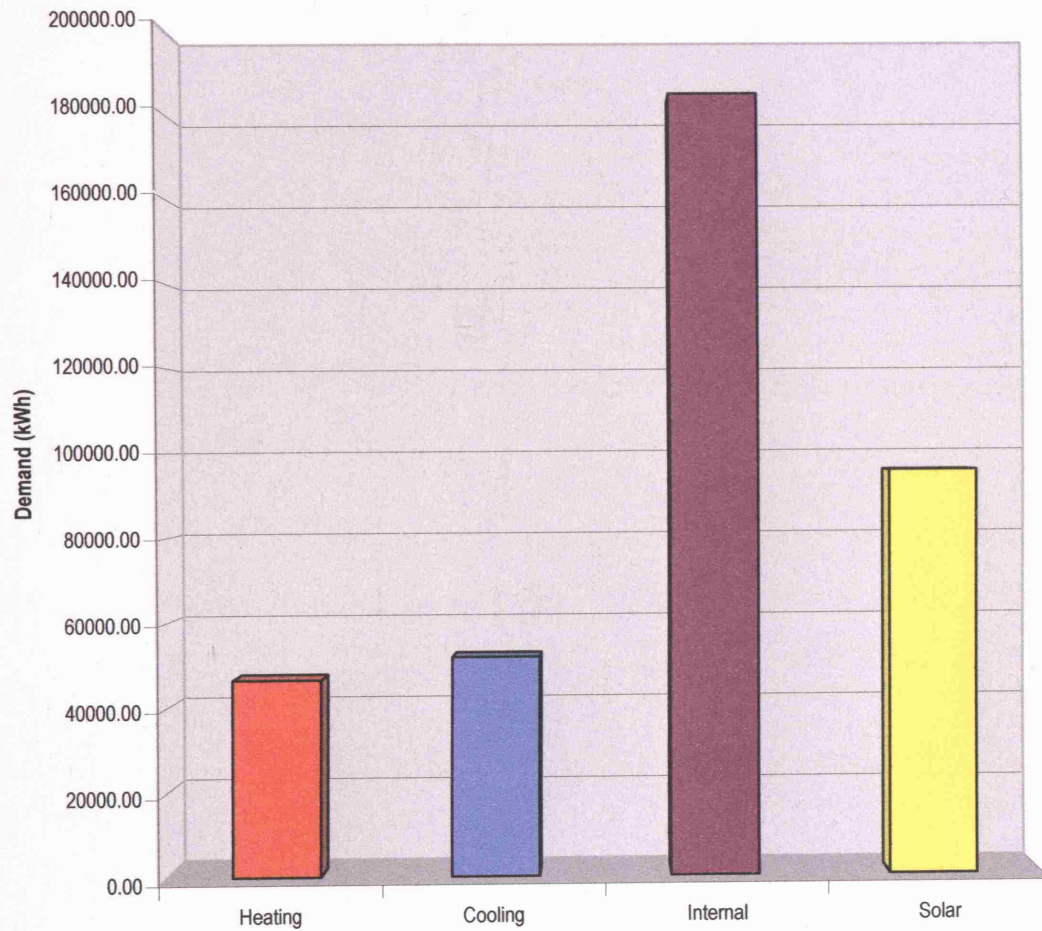
Information on the Base Case model

Annual Total Demand for Nominal Building



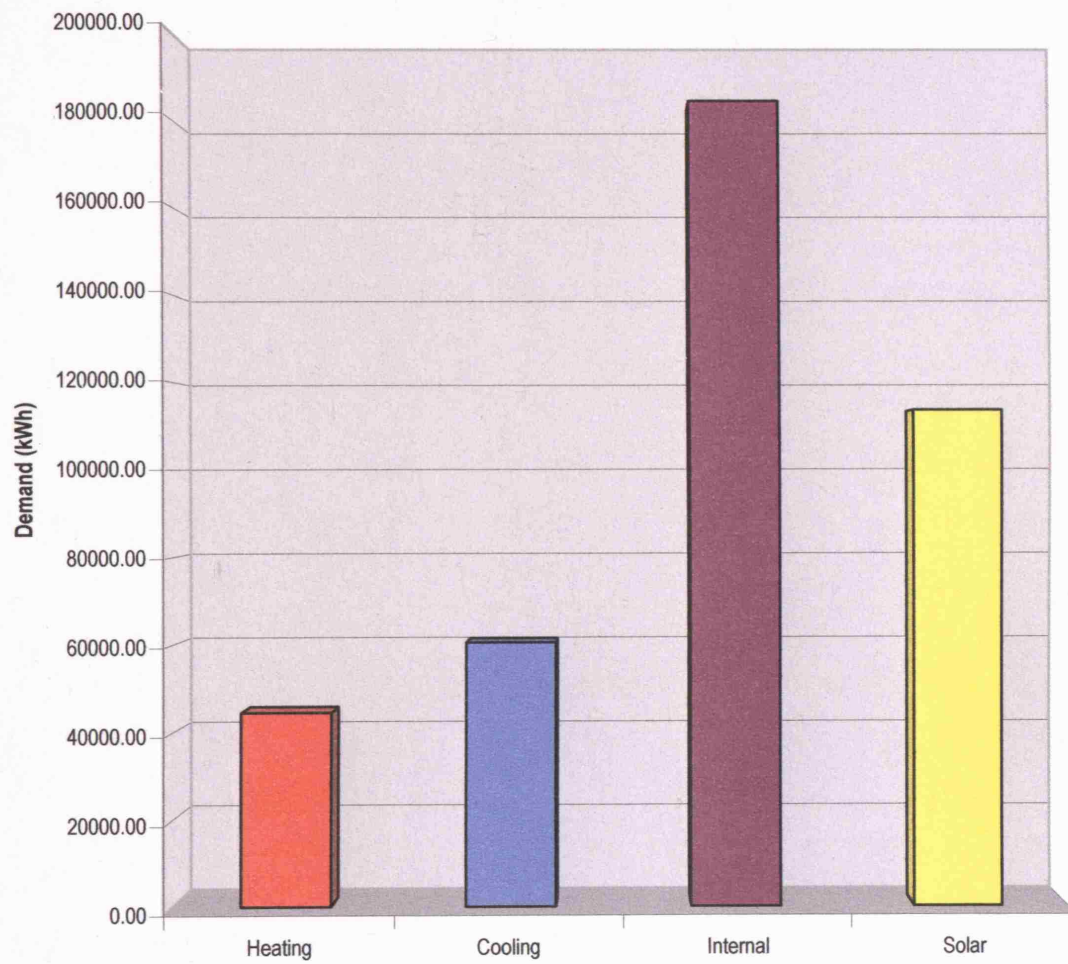
Information on the 1st Case model

Annual Total Demand for TI on North Facade

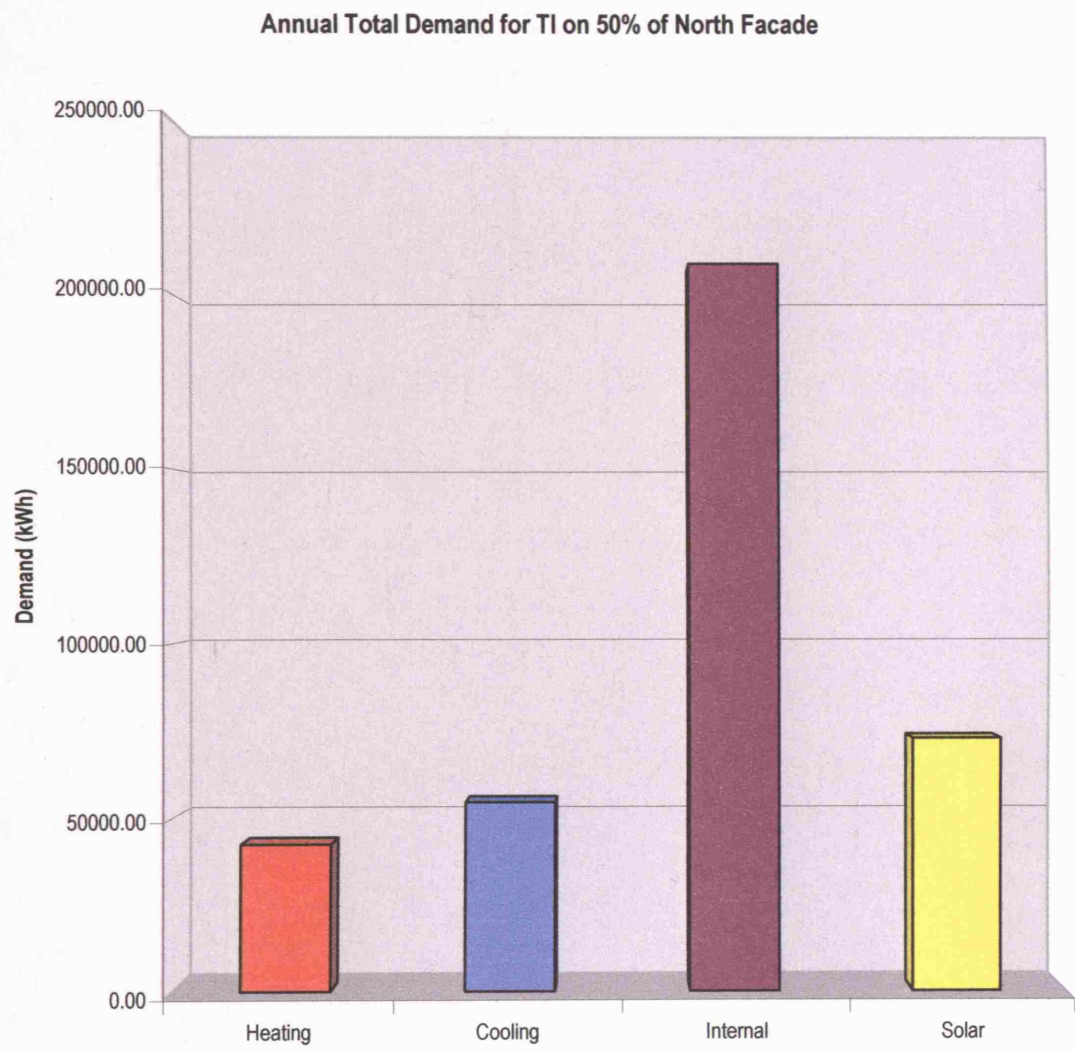


Information on the 2nd Case model

Annual Total Demand for TI on South Facade

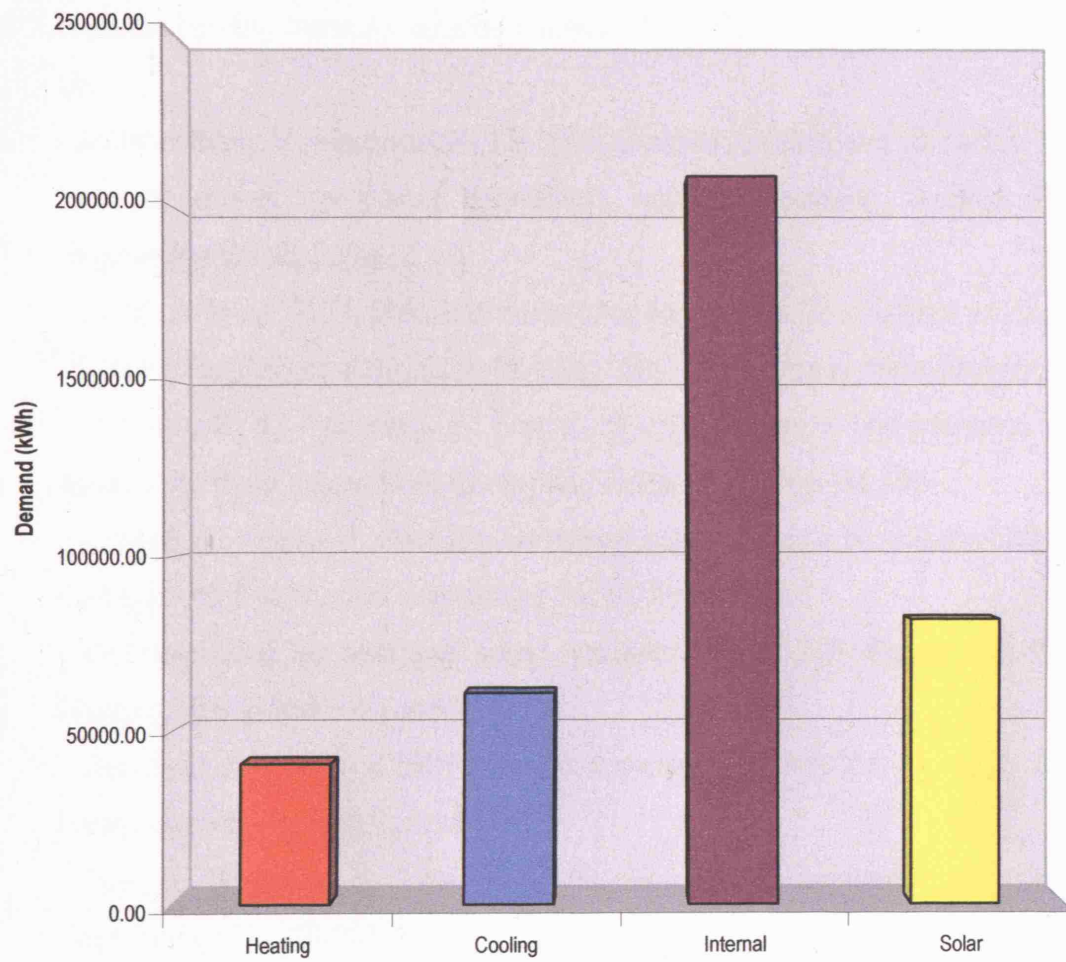


Information on the 3rd Case model



Information on the 4th Case model

Annual Total Demand for TI on 50% of South Facade



Bibliography

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*Note: (All the above sources were lastly visited on 12/ 09/ 2005)